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Design of an autonomous loading & unloading inland barge.

A concept for container transport on the Albert Canal

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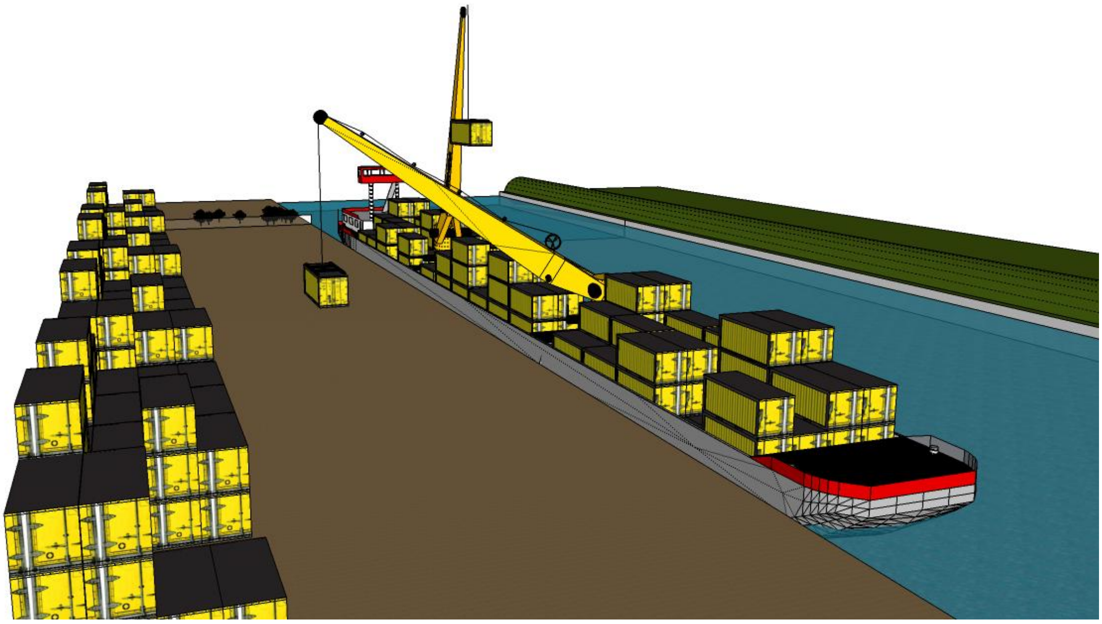

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I Preface

An email with just 20 lines of text and a vague idea about a “container crane pontoon” was the basis for this master thesis. Based on congestion problems near Antwerp and the fact that many companies, located near the Albert canal, do not use the opportunities which the inland navigation sector can offer them, a new concept has been developed.

The department TPR (University of Antwerp) and Marine Technology (Delft, University of Technology) have given me the challenge to develop an economically and technologically feasible inland barge for the transport of containers on the Albert canal and capable of loading and unloading these containers without the use of shore facilities.

I am thankful to all who have contributed in the development of this thesis.

Roderick Gort
Delft/Antwerp, October 2009

II Abstract

The containerization of the freight market has contributed to congested port areas and resulted in a continuous search for new transport concepts. The port of Antwerp is, like many other major ports, encountering challenges with respect to the transport of container to the hinterland. Freight transporters are consequently continuously searching for new transport opportunities. The major goal of this thesis is to develop an inland barge, capable of loading and unloading containers autonomously.

Two different barges have been developed. The first one is named the “Albert canal barge” and is optimized for container transport on the Albert canal, incorporating a limited sailing speed. The second barge is the “Hybrid barge”, which operation range is not limited to the Albert canal because its installed power is sufficient to cope with currents and rapids. The major differences between the two concepts can be found in the propulsion system and the total transport capacity. The Albert canal barge has a capacity of 258 TEU and a Diesel Electric propulsion system. The Hybrid barge is outfitted with a more expensive and more powerful Diesel Direct system for the transport of 242 TEU.

The difference in capacity, propulsion system and acquisition price results in different transport prices. The price for just the transport of containers by barge differs 10% to 15% between the Albert canal barge and the Hybrid barge. The total price of transport, which represents the cost from stack to end destination, differs 3% to 4%.

The comparison of the total transport price for the transport of container by barge with the price for truck transport on a variety or routes show that competing on a short distance is a challenge. The difference between price for truck transport and the transport by barge can be as large as €88 per FEU in favor of truck transport on a transport distance of 70 km.

The developed barges have a variety of price-reduction possibilities to reduce the price difference. The price for barge transport can for instance be reduced significantly if the average time per move in main ports is reduced. Creating a situation where the need for end-transport disappears results in a significant price reduction as well. The price disadvantage of barge transport can be changed to an advantage of €46 per FEU on a relative short transport distance of 50 kilometer by barge. The price advantage of transport by barge increases significantly if the transport distance increases.

The cooperation with terminals and companies along the Albert canal will determine the success of the developed barges. The terminal process will have to be adapted. The availability of containerized freight cannot be quantified. It is expected that the industrialization rate of the Economic Network Albert canal will result in sufficient freight flows. Commitment of companies and terminals located near the Albert canal will be essential and decisive for the success of the developed barges.

IV

III Table of contents

IV List of abbreviations

A_c	Transverse river/canal area
A_e/A_o	Blade area ratio
A_m	Main frame area
A_{tr}	Transom area
B	Width
C_a	Correlation factor
C_a	Appendage drag coefficient
$C_{d\text{-}tr}$	Constant from Terwisga method
C_f	Frictional resistance coefficient
C_p	Prismatic coefficient
C_p	Pressure coefficient
C_{pst}	Prismatic coefficient aft ship
C_z	Constant from bolt method
D	Depth
D_s	Amount of propellers
F_n	Froude number based on length
F_{nb}	Froude number based on width
F_{nh}	Froude number based on water depth
g	Gravitation acceleration
h	Water depth
H_{tr}	Height transom
H_{va}	See figure 6.4
k	Form factor
k_2	Form factor appendages
L_{entr}	See figure 6.4
L_{oa}	Lenght over all
L_{st}	See figure 6.4
L_{wl}	Length waterline
P	Constant from Terwisga method
P/D	Pitch diameter ratio
P_b	Break power
P_d	Propeller diameter
P_{eff}	Effective power
p_o	Pressure at propeller shaft
p_v	Vapour pressure
Q	Constant from Terwisga method
R	Resistance
R_{all}	Scale resistance from model to full scale
R_{app}	Appendage resistance
R_b	Resistance caused by presence of bulb
R_f	Frictional resistance
R_n	Reynolds number
RPM	Rotation rate
R_{shal}	Shallow water resistance
R_{st}	see figure 6.4
R_t	Total resistance
R_{tr}	Transom resistance
R_{vp}	Viscous pressure resistance
R_w	Wave making resistance
S	Wetted surface
S_{app}	Wetted surface appendages
SM	Sea Margin
T	Draught
t	Trust deduction factor
T	Trust
T_a	Draught aft
T_{max}	Maximum draught
u	Speed water flow around hull (bolt method)
V, V_s	Ship speed
V_1	constant karpov method
V_2	constant karpov method
w	Wave fraction number
z	Reduction in water depth
Z	Amount of propeller blades
α_{st}	see figure 6.4
η_{gb}	Gearbox efficiency
η_h	Hull efficiency
η_o	Open water efficiency
η_{shaft}	Shaft efficiency
η_t	total efficiency
ν	Dynamic viscosity
ρ	Density of water

1 Introduction/Background

The inland navigation sector is often referred to as conservative. The fleet is on average over 30 years old and has decreased in size. However the sector is changing. The increasing size of new barges and the continuous search for new transport concepts are good examples of this change.

These changes are a necessary result of a changing market. The transport of freight has encountered a major modal shift towards truck transport over the last decades. Truck transport is quick, flexible and often cheaper than inland navigation. The increase in amount of freight transported by truck has contributed to congested port areas. The congestion has led to a situation where freight transporters are continuously searching for other ways to transport freight.

The European Union has defined goals with respect to the modal split of freight transport. However, the change in modal split has never met these goals despite the fact that the amount of inland terminals has increased considerably in the last decade. The amount of freight transported over the inland waterways has increased, but the inland navigation sector has not been able to recover the lost share in the multimodal split.

Inland barges are small with respect to ocean sailing container vessels. When inland barges visit terminals, the container throughput per visit can be as low as six (Konings, 2007). Combine this with the fact that the income of container terminals mainly depends on container throughput and it can be understood that terminals prefer large container vessels over inland barges.

Small call sizes result in the fact that inland barges encounter large delays in ports. Even with the implementation of scheduled port visits with reserved time-slots at terminals, up to 30% of the round trip time may be caused by port visits (Konings, 2007). Given the fact that visiting a port is not a value adding activity for inland barges, this 30% of a roundtrip time is a threat to inland navigation.

It can be expected that inland barges will get a higher priority and better services at terminals in main ports if their call size increases. The turnover of terminals can increase as a result of the increased container throughput. The situation would be optimal if terminal cranes can load and unload large ocean going vessels, while the barge is capable of loading and unloading independently from terminal facilities. The terminals would not have to supply crane capacity, only quay length. Whenever possible, barges could use shore cranes to load and unload containers since these shore cranes can load containers faster and are probably cheaper then cargo handling equipment installed onboard.

Many companies are located near inland waterways. They hardly ever use the possibilities which the inland navigation sector can offer them. One of the reasons for this is the fact that large investments in for instance quays and loading/unloading equipment are necessary before companies can use the inland navigation as a transport mode. The size of the container flows is often insufficient to make these investments economically viable. It is therefore a challenge to get these containers away from the road to an inland barge. It is more likely that companies will shift their transport modes if necessary investments are minimized to zero. An optimal situation would occur if a company does not have to invest in quays nor equipment.

Inland terminals often use removable cranes or reach stackers to load and unload inland barges. This limits the capacity of the terminal (low transfer rates) and the inland barges (limited outreach in reach stackers) visiting these terminals. Dedicated equipment, designed for loading and unloading containers could result in a higher efficiency at the terminals. For those terminals which already have dedicated equipment, it could add capacity to the existing situation.

These findings lead to the following research goals:

1) *Investigate the economic feasibility of an autonomous loading & unloading container barge on a variety of routes on the Albert canal.*

2) *Design an inland barge for the transport of containers and capable of loading & unloading these containers without the necessity of (high) investments in quays and equipment.*

3) *Calculate the price of transport of the developed barge and describe the demanded changes of the logistical system in which it will operate.*

Chapter two, three and four analyze respectively the inland sector as a whole, the Albert canal and its surroundings from a freight point of view, and possible container handling equipment. A preliminary cost calculation is done in chapter five to investigate the influence of for instance the rate of loading and unloading and the total transport capacity on the transport price.

Chapter six describes the development of the designed inland barge, step by step. The price of transport is calculated in chapter seven. This chapter includes a price comparison between the transport of containers by barge and by truck. Chapter 8 discusses the outcome of the calculations and the implementation of the developed concepts. Chapter 9 concludes this report.

It has to be mentioned that this thesis does not incorporate any changes in the transport market and the inland navigation sector in particular due to the “credit crunch”.

2 Inland Navigation Analysis (SWOT Analysis)

The general pros and cons of the inland navigation sector have to be identified. It is important to know the strengths, weaknesses, opportunities and threats of the inland navigation sector. A SWOT-analysis was performed by the author of this thesis (a.o.) to analyze the inland shipping sector.

STRENGTHS	**WEAKNESSES**
High level of safety Reliable service Lowest external costs Large network of waterways	Accessibility Slow High intermodal costs Minimum sailing distance Limit in scale efficiencies High fixed cost Limited cooperation Low priority in ports
OPPORTUNITIES	**THREATS**
Improved accessibility Economies of scale Increased quality of supply chain management New markets Fiscal stimulations Supply of empty containers	Other transport modes Environmental regulations Insufficient amount of personnel Port congestion Natural constraints

Figure 2.1 SWOT-analysis of inland navigation. (KantoorBinnenvaart, 2009) (Mierlo, 2005) (Cornille, 2005) (Wiegmans, 2005)

Strengths

- *High level of safety*. A relatively low number of accidents occur yearly. It is unlikely that the barge or the freight will be damaged while sailing.
- *Reliable service.* Because of the absence of congestion, delivery times can be "guaranteed"
- *Lowest external costs*. 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. (Steunpunt Goederenstromen (B), 2009)
- *Large network of waterways*. A large network of large and small waterways is available for use. The waterways are almost always available for large freight flows. Congestion is an unfamiliar thing on inland waterways.
- *Fuel efficiency*. Inland barges are powered by engines up to 2.000 kW. These engines have a higher efficiency compared to truck engines. The cost per tonkm is lower for a barge than for a truck.

Weaknesses

- *Mode accessibility*. Getting freight loaded and unloaded from an inland barge is not always as easy as it seems. High investments in quays and loading/unloading equipment are often a necessity for the transport of freight by barge. The amount of freight is often too small to make these investments economically viable. The amount of locations where companies can load or unload their freight is therefore limited. It has to be mentioned that the amount of inland terminals is steadily increasing in both the Netherlands and Belgium. Governmental support is contributing to this.

- *Slow*. With respect to road and rail transport, the transport of containers by inland navigation is slow. With maximum speeds up to 20km/h, time critical freight flows are excluded from the use of inland navigation. The maximum speed on the Albert canal is limited to 12km/h.
- *High intermodal costs*. Quite often inland navigation not the only transport mode. In most cases, a truck will transport the container to its final destination. The change in transport mode is responsible for a large part of the total, door-to-door, transport cost. The choice for inland navigation directly results in an extra modal shift, which is expensive.
- *Minimum sailing distance*. Inland navigation costs less per kilometer because of scale efficiencies. As previously explained, transporting freight by barge results in extra costs for modal changes. To compete with road transport, a minimum sailing distance is required. It is hard to agree upon a minimal sailing distance from which inland shipping should be competitive. This depends for instance on terminals costs and the waiting times of barges in sea ports.
- *Waterway/bridge/lock dimensions limit scale efficiencies*. A clear trend in barge dimensions can be seen: bigger is conceived to be better. The development of the JOWI-class container barge is an example of this. The size of inland barges is often limited by the size of locks, depth of inland waterways or bridge heights. Situations could occur where the demand for freight flows would allow the using of larger vessels, but where this is limited by for instance lock sizes.
- *High fixed costs*. The cost structure of inland barges can be described as fixed. Depreciation, repayments of loans and interest are responsible for the largest part of all costs. They cannot easily be reduced. This results in an inflexible price and limited opportunities to reduce costs. The only ways to reduce costs are reduced loan payment, reduced speed and thus reduced costs of gasoil.
- *Limited cooperation between shippers*. The worst nightmare of an inland shipper is sailing without freight. Sailing empty is a “normal” thing in the bulk market, opposite to the container shipping market. It happens that two barges sail with bulk in opposite directions and sail back empty, where in fact one barge could have done both.
- *Low priority in main ports*. Because of relatively low small call sizes in the main ports, inland barges do not have priority over ocean going vessels. Even with relatively flexible call times at terminals, barges often encounter large delays in ports. Combine this with long travel distances between terminals, and visiting a main port could last up to 30% of the total roundtrip time. (Konings, 2007)
- *Limited lock operating hours*. The locks located in the Albert canal are operated 6 days a week, 24 hours a day. Preferably, the locks are operated on a 24/7 basis. This would increase operating opportunities for shipping companies.

Opportunities

- *Improved accessibility of (small) waterways.* The availability of waterways does not necessarily mean they are accessible. Increased bridge heights and canal depths could increase their accessibility and could increase therefore the opportunities for inland navigation.

- *Economies of scale.* A clear trend can be observed in the inland navigation sector: the barges are becoming bigger. Since it is not possible to increase speed, and therefore to increase the amount of roundtrips per year and thus the transported capacity, the size of the barges has to be increased. The JOWI-class container barge is an example of this. Where the waterways “allow” an increase in size, it is likely that such will happen.
- *Increased quality of supply chain management (modal shift to inland navigation).* The amount of inland terminals has increased considerably in the last decade. This has increased multimodal opportunities for many companies. These companies are however not aware of these possibilities or not willing to change because “things are going pretty well right now”. Companies often chose for truck transport because it is the easy option. An increase in awareness could lead to a higher level of supply chain management and an increase in the use of multimodal transport.
- *New markets (cars, recycling, waste).* The inland shipping sector is “discovering” new markets. The transport of cars is a perfect example of this. Nowadays, the limited bridge height on the Albert canal is limiting the possibilities to transport for instance Ford cars to and from Genk. A bridge height increase might result in a shift from car transport to inland navigation.
- *Fiscal stimulations.* It is possible to improve the position of inland shipping with respect to for instance truck transport by subsidizing freight transported by inland barge. Subsidizing a modal shift towards inland navigation results in lower cost for society (external cost). Taxes can be reduced, or shifted in favor of inland navigation.
- *Supply of empty containers.* The availability of empty containers is of great importance to the overall economic success of inland barges. Empty containers can improve the occupation rate when there is an imbalance in freight flow. Sailing empty is not an option, and empty containers will have to back anyway. The cost of transport can be spread amongst a higher amount of containers and the price of transport will therefore be lower.

Threats

- *Other transport modes.* The biggest threat to the inland navigation level is the competition with other transport modes. The flexibility of truck transport is a hard thing to compete with. An increase in sustainability of truck transport must be seen as a threat as well.
- *Environmental regulations.* The emission of sulphur and pm-10 particles is seen worldwide as an important reason for global warming, or the so-called greenhouse effect. Regulations are implemented and limiting emissions. This results in the fact that (relatively) high investments have to be done on small, old inland barges. It can be questioned whether these investment are economically viable since they are relatively high with respect to the yearly turnover and the value of the barge, and therefore with respect to the yearly earnings of the inland barges.
- *Insufficient amount of qualified personnel.* This threat is twofold. The first aspect is the amount of families who own and sail an inland barge is decreasing. They choose to stay ashore. The second aspect is that insufficient amount of qualified personnel

graduates from school every year. Not enough people choose for a life onboard an inland barge.

- *Port congestion.* The amount of freight handled has increased tremendously; the way freight is handled has changed as well. With the increase of freight, ports have started to become increasingly congested. Waiting times have increased, quays are congested and dwell times can be relatively long with respect to overall transport times. Summarizing, the increase of container traffic has had its effect on container handling in ports.
- *Environmental constraints.* A low water level limits the sailing draft of barges and therefore the transport capacity. If water levels are too high, currents will increase and this will limit the sailing possibilities of inland barges as well. It water levels are really high, it is likely that sailing will be prohibited by governments.
  Another force of nature is temperature. Last winter (2008/2009), temperatures have been low resulting in blocked rivers and canals because of ice. For instance the Main-Danube channel has been blocked for weeks.

The SWOT analysis shows that the inland navigation sector encounters a variety of threats. The amount of weaknesses is significant. The determined weaknesses and opportunities do however create a basis for the design of an autonomous loading & unloading inland barge.

The initial idea of the concept is supported by the outcome of the SWOT-analysis. Reducing terminal costs should be possible. The behavior of terminals with respect to the developed concepts could be improved (higher priority). Scale efficiencies might be obtained due to increased transfer rates.

Although the results of the SWOT analysis are shown in an arbitrary order, it can be assumed that the *intermodal costs* and the *low priority in ports* are the main weaknesses of (container) inland shipping. The largest opportunities are assumed to be the *economies of scale* and the *improved accessibility* of companies along the Albert canal. Changing these weaknesses and opportunities into strengths should therefore have the main focus in the development an autonomous loading & unloading inland barge.

3 Albert canal Freight Analysis

The availability of freight is of great importance for the developed barges. This chapter will describe the Economic Network Albert canal and the development of freight transport over the Albert canal in the last decades.

3.1 The Albert canal

The "Albert canal" is the canal which connects Liège with Antwerp and the Westerschelde. The canal was opened in 1939 and has a total length of 129 kilometers. It was designed to increase inland navigation opportunities whereas the Kempener kanalen were no longer sufficient for the transport of freight between Antwerp and Liège. Originally designed for inland vessels with a maximum deadweight of 2,000 tons, the canals' capacity was extended in the seventies to a maximum of 9,000 tons.

The containerization of the freight transport market has resulted in an increasing amount of container transport to and from Antwerp on the Albert canal. The maximum dimensions of inland vessels on the Albert canal are shown in table 3.1. The maximum height of 6.70 meter limits the amount of container layers to three. In 2007, a two-phase, eight year building program was started to increase bridge heights to at least 9.10. Inland vessels will be able to transport four layers from the year 2015 on.

Dimension	Max.Allowed	Max.Available
Length	190 (m)	200(m)
Width	12.5(m)	24(m)
Height	6.70/9.10(m)	6.70/9.10(m)
Depth	3.40(m)	5.00(m)

Table 3.1 Maximum dimensions Albert canal (PC Navingo 4.5, 2006)

The areas surrounding the Albert canal are highly industrialized. The following picture gives a schematic overview of the main industrial areas.

Figure.3.1 Overview of industrial areas Albert canal (derived from (Iris/Bulk Consultant WES, 2006)

The main junctions are located near Antwerp, Herentals/Geel-punt, Tessenderlo and Genk. These junctions are recognizable by the size of the companies located there, as well as by the availability of transport infrastructure (road/rail/inland waterways).

The following graph shows the existing transport infrastructure near the Albert canal.

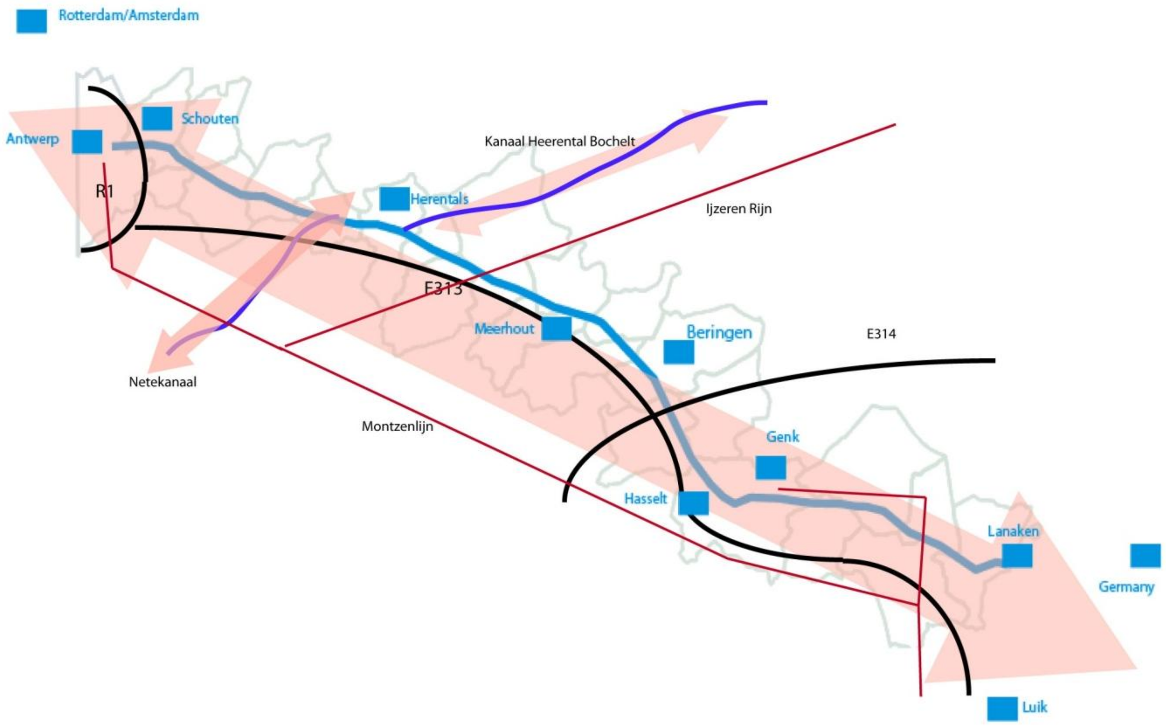


Figure 3.2 Existing transport infrastructure(Derived from (Iris/Bulk Consultant WES, 2006)

The highway E313 is of great importance for the industrial zones around the Albert canal. In fact, it is the most important competitor for the inland navigation sector on this route. Various junctions with for instance the N19 (to Geel), the E314 and the channel Herentals-Bocholt create different multimodal possibilities. The Iron-Rhine and the Montzen lijn connect Antwerp and the Channel to the German Ruhr area by rail.

As can be observed, all transport modes (except air) are available near the Albert canal. The competition between these modes is fierce. The combination of a highly industrialized channel and a large hinterland (e.g. Ruhr-area) create an enormous demand for transport. How enormous is this demand, where does it originate and what are the destinations of these freight flows? The following part of this chapter tries to answers these questions.

3.2 Freight on the Albert canal

The next part of this chapter will analyze freight traffic flows on the Albert canal from 1977 to 2007. It will show directions of traffic flows as well as the development of their size over time.

The Albert canal is an inland waterway with many, highly industrialized areas near its banks. In fact, many areas were developed at their specific location because of the Albert canal.

The following figure shows the development of the total amount of transported freight on the channel.

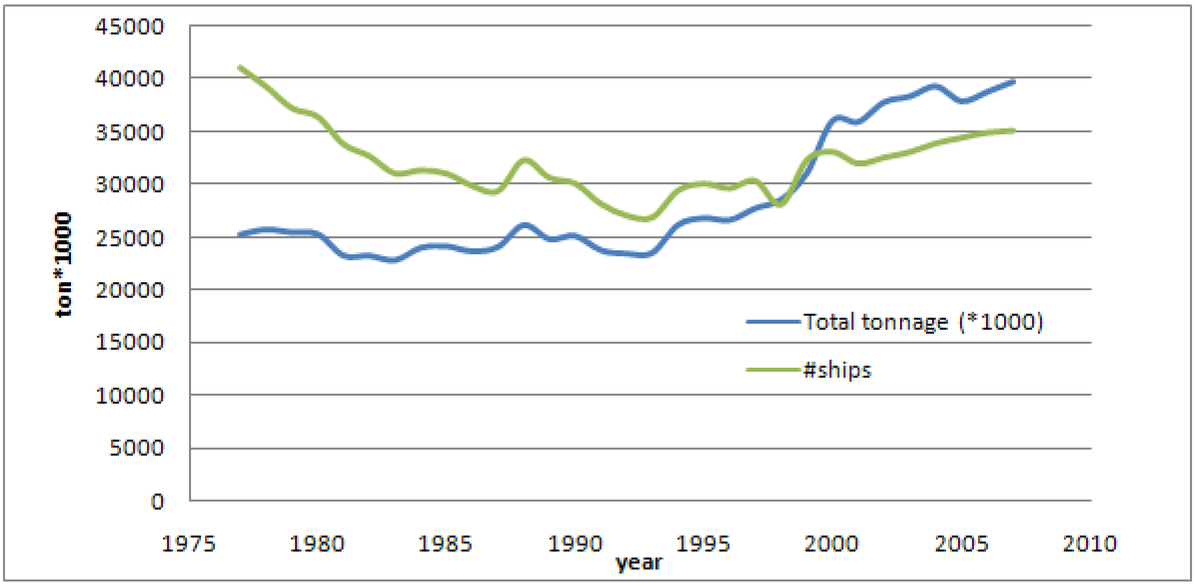


Figure 3.1 development of freight transport on the Albert canal (nv De Scheepvaart, 2007)

The first thing which becomes clear from this graph is the fact that from 1975 to the nineties, the amount of freight has not grown considerably. From 1995 on, the amount of freight has increased by almost 60 percent. The amount of ships transporting freight has decreased significantly during the period 1977-1995, while the amount of freight has not decreased. The size of the ships sailing the inland waterways, must thus have increased. This trend has continued over the last 15 years, but the increase of 60 percent of transported freight could not just be covered by the increase of vessels sizes. The total number of vessels has increased as well.

The *total-tonnage*-number could be misleading if for instance all vessels on the Albert canal are heading for the Ruhr-area in Germany. This would mean that the industry surrounding the Albert canal is not using the canals' opportunities for intermodal transport. It is therefore more interesting to see the origin and destination of freight transported on the Albert canal. Or firstly see, which part of the transported freight is loaded or unloaded on the Albert canal. Figure 3.2 shows this.

From this figure, it can be concluded that about 50% of the freight transported on the Albert canal is so-called through transport, which means the freight isn't loaded or unloaded on the Albert canal. The *through*-tonnage originates from Liège and the Ruhr-area with destination Antwerp and vice versa.

It can be observed that the unloaded freight outnumbers the loaded freight by a factor three. This is partly the result of the fact that there is more freight being imported into Antwerp then exported. Belgium is a relatively small country with a large port. The amount of freight coming into the port outnumbers the national need for commodities and resources. It is therefore logical that the offloaded freight outnumbers the loaded freight.

Another reason could be that the industry is using the canal for its raw materials but uses a different transport mode for its produced (end) products.

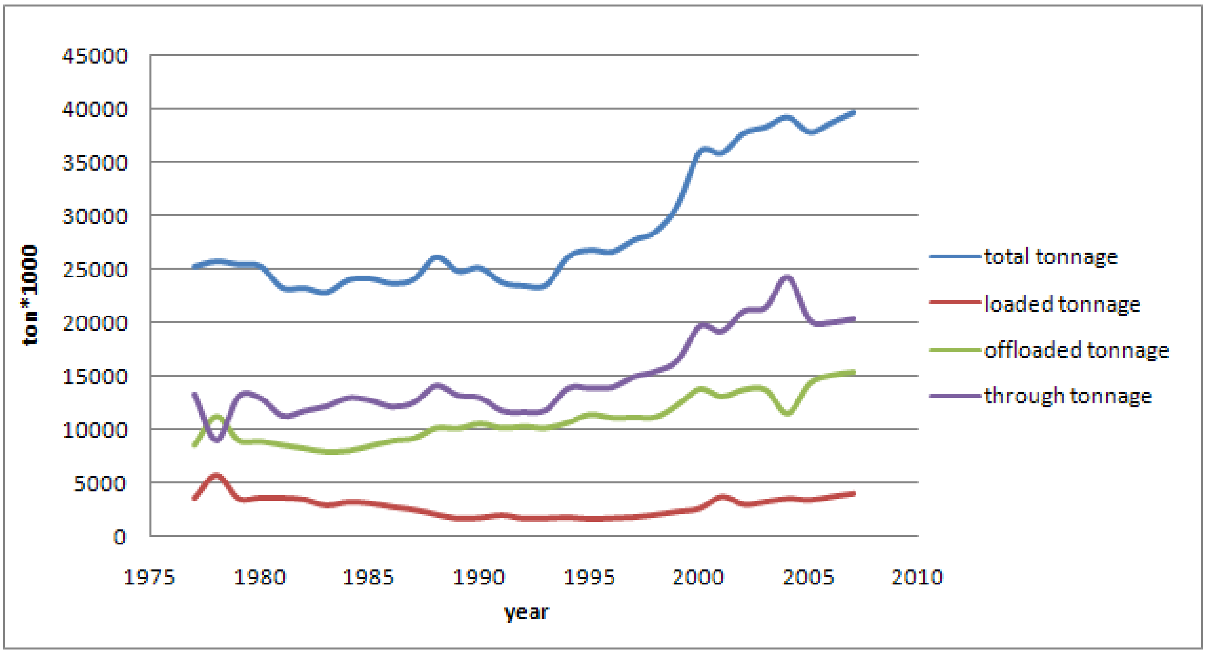


Figure 3.2 loading/offloading-split total tonnage (nv De Scheepvaart, 2007)

Albert canal	Upstream	Downstream
Total transported freight (*1000 ton)	27,324	11,874
Loaded tonnage (*1000 ton)	698	3,255
Unloaded tonnage (*1000 ton)	12,569	2,801
Loaded and unloaded on Albert canal (*1000 ton)	19	52
Partial through transport	2,325	1,942
Total through transport	11,723	3,951

Table 3.2 Specification of freight flows up- and downstream (nv De Scheepvaart, 2007)

Table 3.2 separates the upstream freight flows from the downstream flows. It confirms the previous figures which state that the transport flow from Antwerp to Lanaken is much larger than the freight flow towards Antwerp. This observation is important to keep in mind. For the success of transport concepts, the availability of freight on an entire round trip is of great importance to the economic success of the concept. A lack of available freight in parts of a roundtrip could seriously threaten the economic feasibility of the concept.

Figures 3.1 and 3.2 do not specify the kind of freight. The following figure gives an overview of the various types of freight plotted against transported tonkm. This figure clearly shows that building materials (mainly sand) is a large portion of the total amount of tonkm transported on the Albert canal. Bulk materials (sand, cement, iron ore, asphalt grid, oil, chemicals, and fertilizer) are responsible for the main portion of transport on the Albert canal in Belgium.

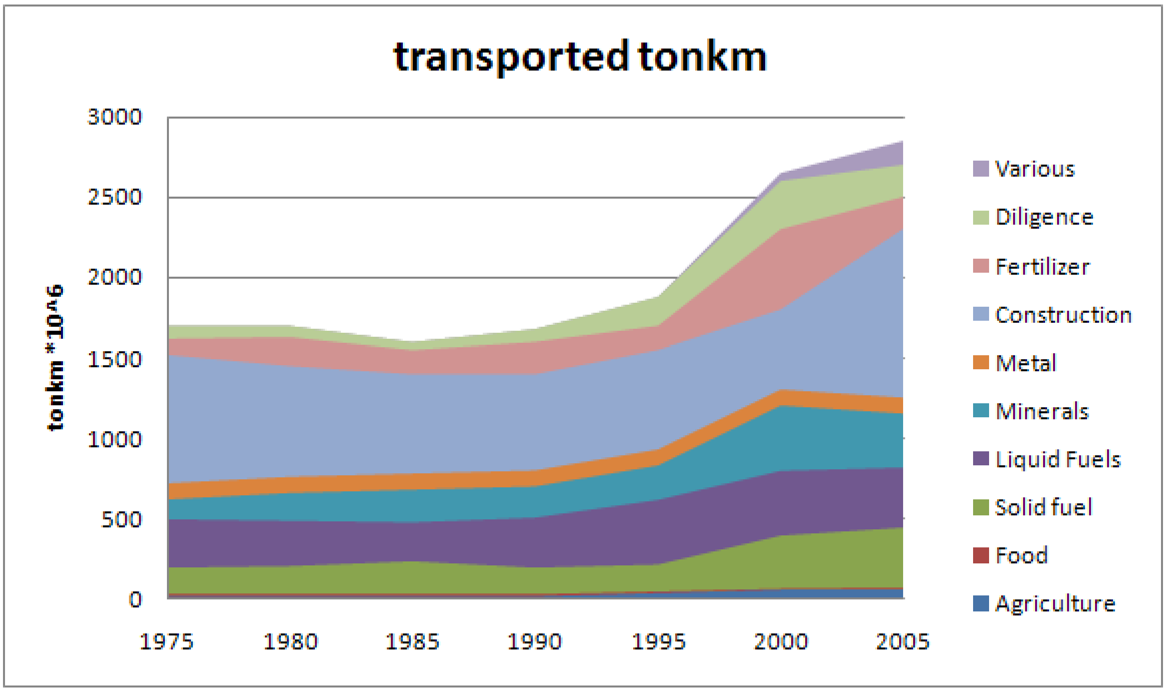


Figure 3.3 development of tonkm per freight type (derived from (nv De Scheepvaart, 2007)

It is not possible to derive the container flow from this figure. The following figure shows the development of the containers handled in Flemish inland waterway container terminals:

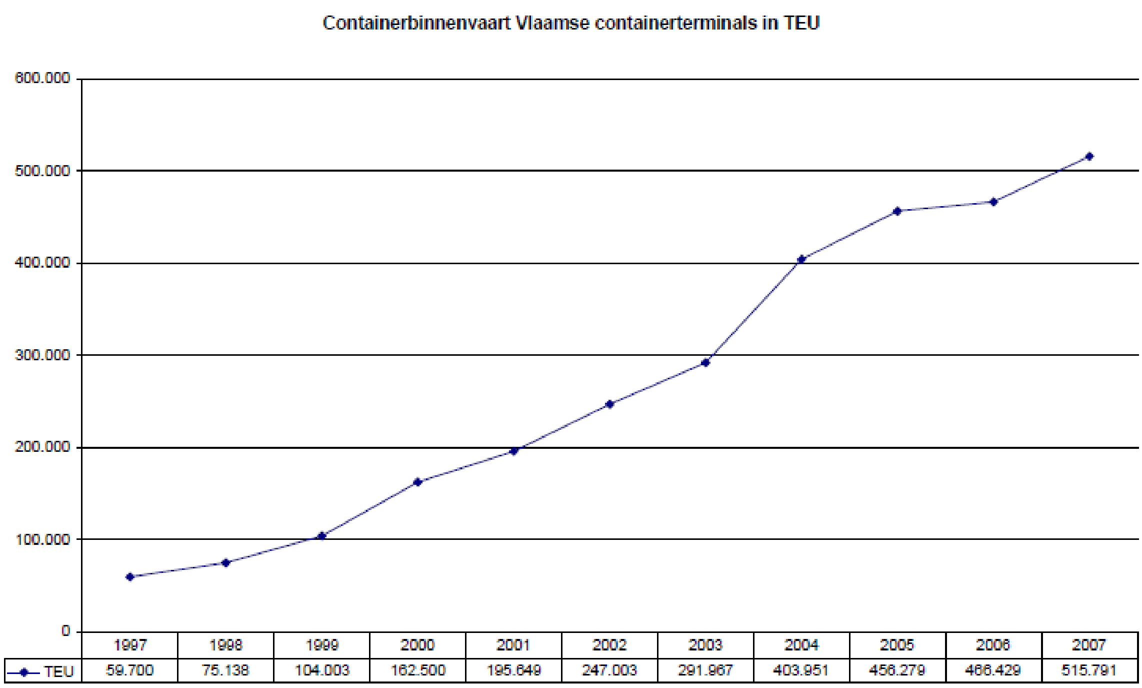


Figure 3.4 container terminals inland navigation (Promotiebinnenvaart.be)

As can be observed from this figure, the amount of containers handled by inland terminals has been multiplied by a factor nine in a period of eleven years time. The “Quay wall program” (Quay wall program, 2005) has contributed to the fact that the amount of inland terminals in Belgium has increased considerably over the last decade. This program stimulates the building of these terminals by subsidizing them. The increased amount of terminals has contributed to the multimodal possibilities of many companies located nearby these terminals. The cost of end-transport has been minimized (to sometimes zero) and has therefore increased the competitiveness of transport chains which include inland navigation.

The most important inland terminals, located near the Albert canal, are:
- Water Container Terminal (Meerhout),
- Euro Shoe container Terminal (Beringen)
- Gosselin Container Terminal (Schoten)
- Inland Terminal (Genk)
- Port de Liege, (Liege)

The locations of the terminals can be found in figure 3.5.

The following tables show the main (significant) container flows (in TEU) on the Albert canal. Shown are the container flows over 5,000 TEU per year.

To↓ From→	**Antwerp**	**Schoten**	**Meerhout**	**The Netherlands**	**Stein**	**Genk**
Antwerp	**X**	7,514	39,930		5,770	11,292
Schoten	5,442	**X**				
Meerhout	47,633		**X**	35,372		
The Netherlands		15,765	8,926	**X**		
Stein					**X**	
Genk	17,948					**X**

Table 3.3 Main container flow with ***loaded containers*** (nv De Scheepvaart, 2007)

To↓ From→	**Antwerp**	**Schoten**	**Meerhout**	**The Netherlands**	**Stein**	**Genk**
Antwerp	**X**		46,036			14,056
Schoten	6,261	**X**				
Meerhout	21,455		**X**			
The Netherlands			7,424	**X**		
Stein					**X**	
Genk	5,580					**X**

Table 3.4 Main container flow with ***empties*** (nv De Scheepvaart, 2007)

The container flow to and from Rotterdam and Amsterdam is summarized as “the Netherlands”. These tables seem to indicate an absence of freight transport between Rotterdam and Antwerp. However, the contrary is true. Since this thesis focuses solely at container transport on the Albert canal, the transport on the Rijn-Schelde trajectory is excluded from the data given above. In fact, the container flow between Antwerp and Rotterdam is more than one million TEU. In 2007, 353,012 TEU were transported on the Albert canal. Appendix 3.1 gives a complete overview off all containers transported on the Albert canal in 2007, specified by their origin and destination.

The place named Lanaken is the spot where inland vessels with various destinations will split. Those with destination Born/Stein/Germany will head north, those headed for Liège south. In figure 3.5, the container flows destined abroad are represented by the arrow to Lanaken.

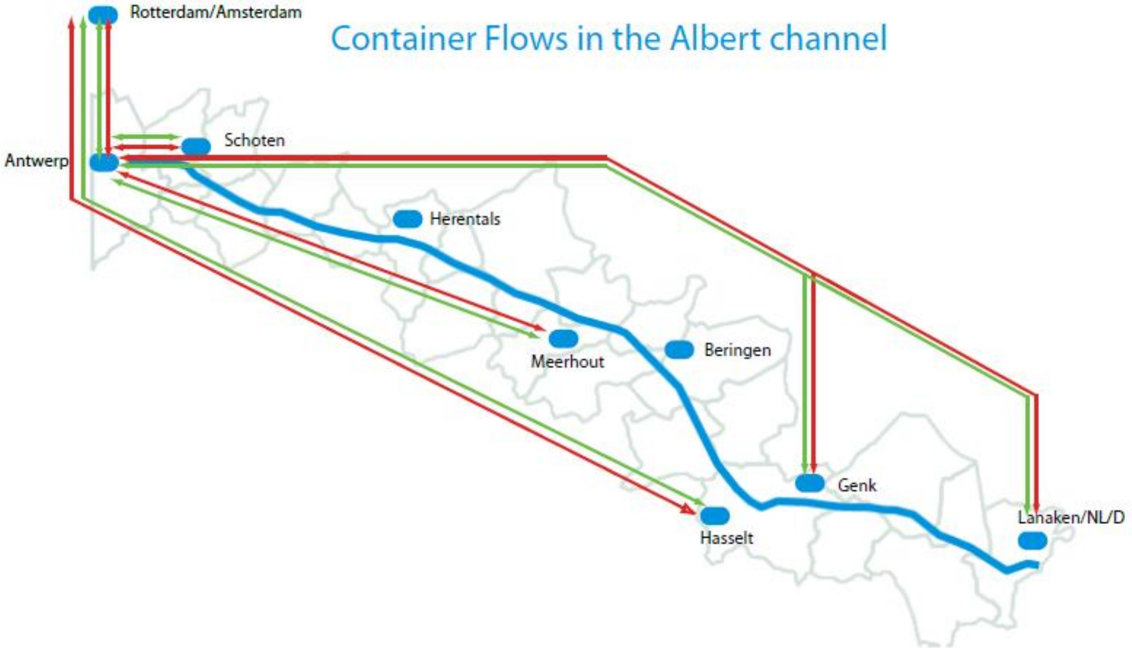


Figure 3.5 Overview significant container flows Albert canal

The flow of empty containers is shown as well in this figure, since it is of great importance to the economic feasibility of inland navigation. As stated before, this will be explained later on in this report. It is noticeable that there is no significant flow of empty containers from Schoten to the Netherlands. All other full container flows have their corresponding flow of empty containers.

The existing flow on the Albert canal is the first part of the potential transport flow of the new inland navigation concept. The second part exists of freight which is nowadays transported by truck. The influence of rail transport on the developed concept is neglected, since its absolute size is less than 8% of the total volume (Port of Antwerp, 2007) and rail transport is merely used for long distance transport. It is therefore not likely that the developed concepts will compete with rail transport or make a significant modal shift from rail to inland navigation happen.

It is a lot more difficult to get a clear overview of container traffic on for instance the E313. There is no clear information on origin and destination of truck container transport. Available are the traffic counts (NL: *verkeerstellingen*) of various locations on the E313 and surrounding highways. These give only to the total amount of traffic, not specified by their kind, origin and destination. They are therefore of no use for this research.

It is interesting to take a look at the split of the Flemish economy in general, as well as to the modal split of freight handled in the Port of Antwerp. The following three figures show the modal split for the Flemish area in total. It can be observed that the rail mode has decreased significantly over the last 18 years. This does not mean that the tonnage of transported freight has decreased, only the percentage of the total. The inland navigation part has not seen an increase either. These modal splits show that the share for truck transport has increased from 1990 onwards.

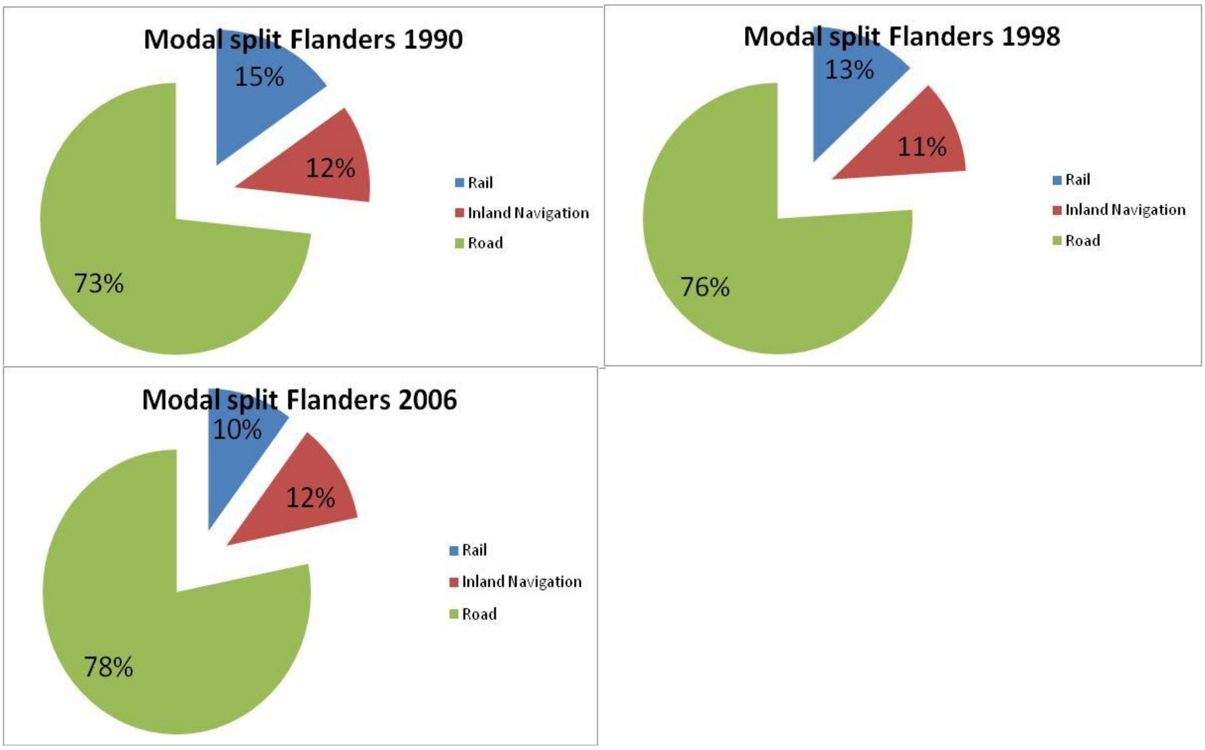


Figure 3.6-3.8 modal split freight transport in Flanders (Steunpunt Goederenstromen (A), 2007)

From these figures (3.6-3.8), it is not possible to quantify freight transport by truck near the Albert canal. The following figures (3.9-3.11) show the development of the modal shift of all freight handled by the Port of Antwerp. The third figure shows the modal split of container traffic in the Port of Antwerp.

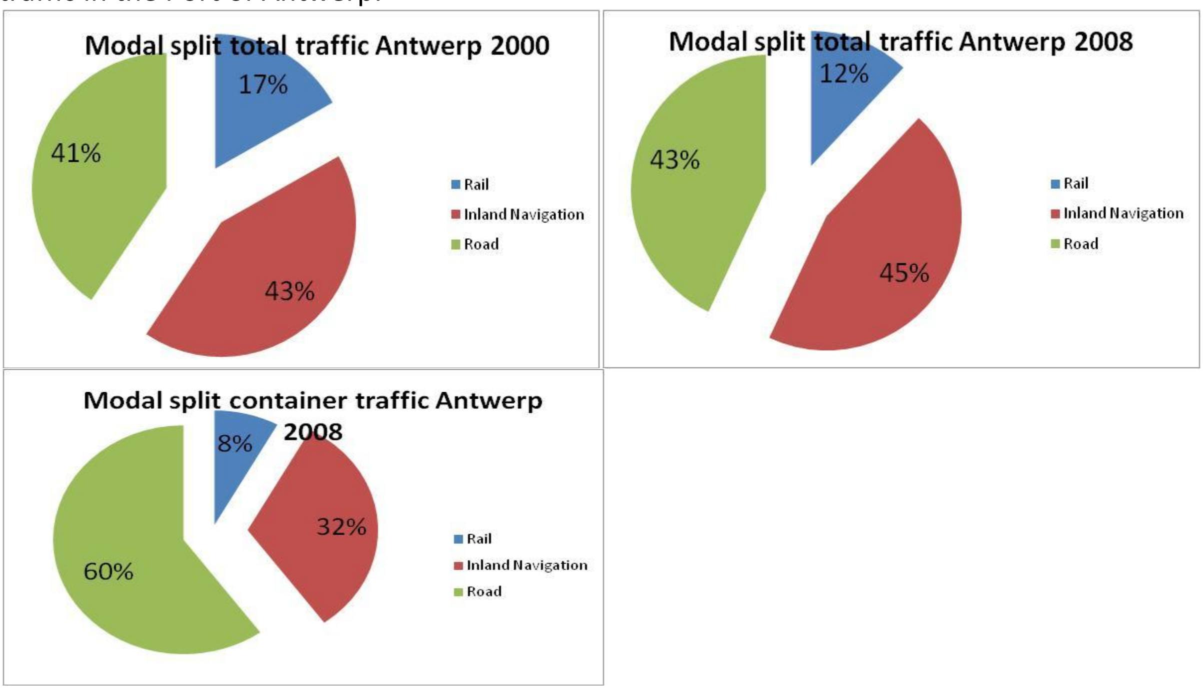


Figure 3.9-3.11 modal split freight transport Port of Antwerp (Steunpunt Goederenstromen (A), 2007) (Port of Antwerp, 2007)

Figure 3.9 and 3.10 show an increase of freight transported by barge. The modal split for container transport is given for those containers which are not solely “transshipped”. About 18.8% of all containers entering Antwerp by oceangoing vessels leave through the same door as they entered the river Scheldt.

A significant difference between the modal split of all freight handled by the port of Antwerp and the container split is the inland navigation part. 60% of all containers entering the Port of Antwerp are transported by truck. The modal split for truck transport (of all freight transported by barge) is only 43%, which means bulk transport is outnumbering the tonnage of containers transported by barge. As previously observed, the total amount of containers transported on the Albert canal is increasing and as a result of that, the modal split is changing as well. The high percentage of container transport by truck indicates the potential market for other transport modes. The roads surrounding the Port of Antwerp are becoming increasingly congested whereas the maximum capacity of the Albert canal is not yet in sight if bridge heights are increased.

In 2007, the Port of Antwerp transferred more than eight million TEU. This number must be reduced by the percentage of transshipped containers. Multiply the result with the modal split for inland navigation and the total amount of containers transported by inland vessels is known. This is 2,13 million TEU (in 2007). Likewise, the share of other transport modes can be calculated.

The total amount of containers transported on the Albert canal is around 355,000 TEU (nv De Scheepvaart, 2007). The most important inland navigation container flow exists between Rotterdam and Antwerp. Around 1.37 million TEU are transported yearly between these ports. This means that around 760,000 TEU’s are shipped by inland vessels to for instance Zeebruges, Flushing, Ghent and of course various destinations along the Albert canal. The Albert canal is responsible for 47% of all TEU’s transported on inland waterways in Belgium.

Transport mode	**Percentage(%)**	**TEU**
all	100	8,176,614
Transshipment	18.8	1,537,203
Road	48.8	3,990,188
Inland Navigation	26.1	2,134,096
Rail	6.4	523,303

Table 3.5 transport modes and amount of containers(2007)

The potential market for the developed concepts is the sum of the existing market of containers transported by barge plus a part of the containers which are nowadays transported by truck. As stated before, it is very hard to quantify this part of the market potential. As can be observed from table 3.5, the total amount of TEU transported by truck from and to Antwerp is around four million.

From Antwerp to:	Total TEU (2002)	Total TEU (2007)	% by truck	% by barge	TEU by barge
Switzerland	37,400	63,954	18	16	10,233
Austria	19,500	33,345	46	5	1,667
Poland	18,700	31,977	67	1	320
Czech Republic	14,400	24,624	61	6	1,477
Italy	41,600	71,136	38	0	0
Germany	348,000	595,080	76	11	65,459

Table 3.6 overview of container flows from Antwerp to destinations abroad and vice versa (Gerrits, 2007)

Table 3.6 gives an overview of container flows to and from Antwerp in 2002 and 2007. The 2002 data is coming from the report "dynamic port planning under competition (Gerrits, 2007). In this report, data is derived from origin-destination matrices for container transport to and from the German hinterland for the 4 largest ports in the Hamburg-Le Havre range. These numbers are scaled linearly with the overall growth of container transport in the port of Antwerp from 2002 to 2007. In this period, the increase of container throughput in Antwerp has been 71%.

From this table, it becomes clear that the container flows to Austria, Poland, Italy and the Czech Republic can be ignored. The container flows are so small that their significance with respect to the total freight flow is minimal and can therefore be neglected. The size of these flows is not sufficiently large to let the developed concepts depend on them. According to the Scheepvaart NV, only 60 containers were transported over the Albert canal to Germany. Table 3.6 states that there should be a container flow of about 65.000 TEU to Germany. It is likely that this is a flow over Dutch inland waterways, not over the Albert canal. The source of this table focuses on freight flows towards Germany from the four largest ports in the Le Havre-Hamburg range and does not mention any flows from France to Germany.

As previously mentioned, it is a challenge to quantify container flows to and from the regions around the Albert canal. The necessary figures were not available for this thesis. The data which is available is categorized into freight type and has an origin destination matrix based on counties. These matrixes are based on data from 2004. To get an idea about these flows in 2007, they have to be multiplied by a factor 1.045. This number originates from FOD Economie (2009) and represents the growth in transported freight within Belgium.

The Flemish freight model which is used by the department TPR (UA) does describe the freight flows within Flanders. The freight is specified into ten categories. The model does however not specify whether the freight is containerized or not. It is therefore not possible to specify the existing container flows from this model. The freight model does however show significant freight flows throughout Flanders, and more specific, around the Economic Network Albert canal (ENA).

Assuming containerization rates could lead to an expected demand for transport capacity. This has not been done since it is extremely hard to qualify these assumptions. The outcome of calculations based on these assumptions would therefore not be reliable.

4 Barges and Freight Handling Equipment

Exploring the freight market of the Albert canal was the first step towards a new inland barge capable of loading and unloading containers autonomously. This chapter will explore and evaluate existing barges with freight handling equipment as well as other concepts from the past in order to come up with an optimal loading & unloading concept for the developed barges.

This chapter has been written to investigate existing concepts and see where opportunities for new concepts can be found.

4.1 Parameters

One of the most important and decisive factors for the success of the barge is the container handling equipment. The following equipment parameters are important when evaluating loading/unloading equipment:

- *Dimensions in sailing condition.* This is of great importance to the concept because the size of the equipment is directly responsible for a loss in container capacity. This loss in capacity is a direct threat to the economic success of the barge. The height of the equipment in sailing condition cannot exceed 9.10 meter since this is the minimum bridge height on the Albert canal. The width while sailing is limited to the ship's beam and maybe even less.

- *Dimensions in loading/unloading condition*. One of the most important parameters when in loading/unloading condition is outreach. In what range is it possible to handle containers? Can they be placed just on the quay? Or is it possible to place the containers 20 meter from the waterfront? And what is the maximum weight, or equivalent moment, the equipment can handle?

- *Weight*. The weight of the equipment is important because it results in a higher total weight for the vessel. When compared to an inland barge transporting equal-sized containers, the developed concepts will have additional weight due to the presence of the loading/unloading equipment. This additional weight will result in higher fuel consumption.

- *Container throughput (containers/hour).* It is likely that loading and unloading of containers will be responsible for a significant part of the roundtrip time. The pace of loading and unloading is therefore an important parameter for the developed concepts.

- *Container size*. Not all equipment types are capable of handling 40 or even 45 foot containers. The equipment must be able to move up to 35 ton, since this is the maximum weight of containers.

- *Price*. This parameter is the most obvious one. Purchasing loading and unloading equipment is expensive. It can be questioned whether this is economically feasible. The invested amount of money will have to result in profit, or said otherwise: in a positive return on investment.

- *Pressure on quayside*. If an equipment type uses some sort of stabilization device on the quay, the pressure on the quay side could become that large that a quay will have to be built, or investments have to be done to strengthen the surroundings.

- *Attainability.* Some concepts are fully developed and have proven to be successful in real life. Some concepts have never passed the stage of concept and the implementation of these concepts will inevitably lead to development costs. These additional costs are a threat to the economic success of the inland barge on which the concept should be installed.

Some parameter will be ignored when choosing the optimal way to load and unload containers. It is for instance very hard to say something about maintenance of the systems. Both cost and loss of time due to maintenance are not easily quantifiable. It is assumed as well that every type of equipment is capable of positioning a container sufficiently precise to put it onto a chassis or another container.

4.2 Principal differences

Loading and unloading of containers can be done in a various ways. The way containers are handled can be divided into fundamentally different categories. The most common way is categorized as “Lifting”. Another possibility to move freight ashore is “rolling”. Figure 4.1 shows these equipment types in a schematic way, including some existing and non-existing examples of these equipment types.

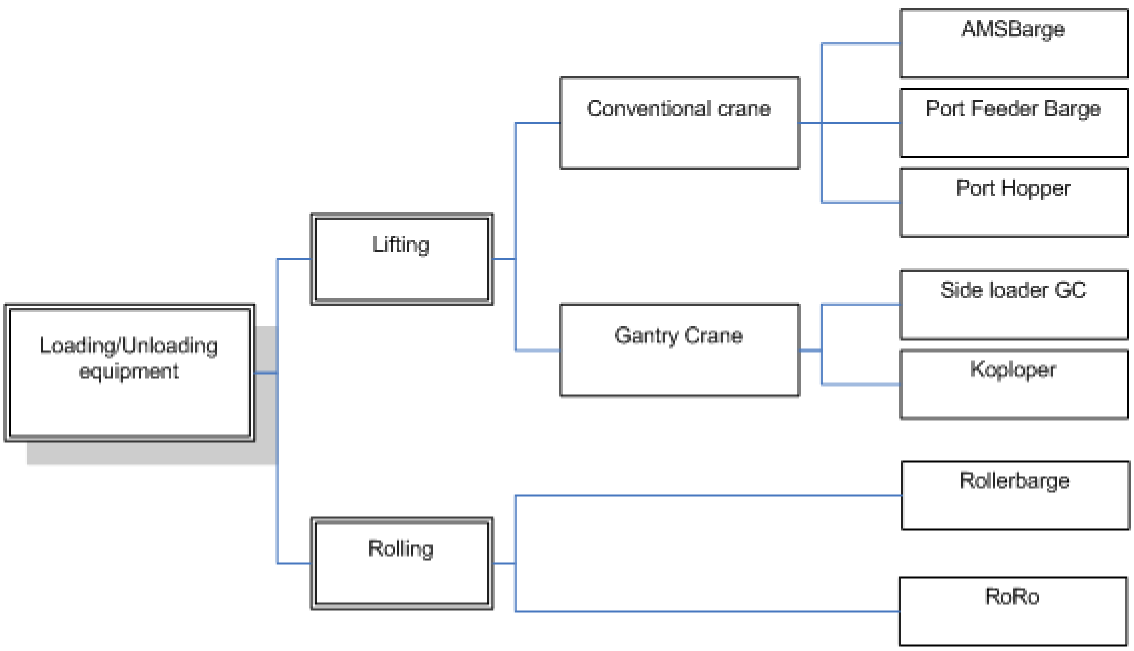
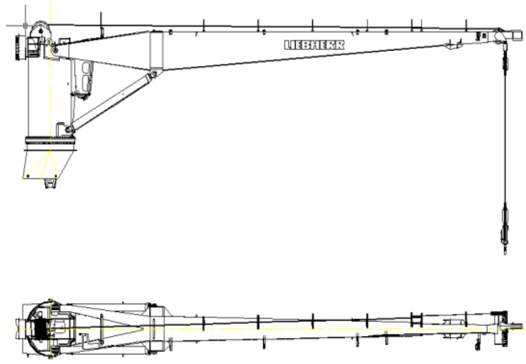


Figure 4.1 Schematic overview loading/unloading equipment

4.2.1 Conventional lifting

Lifting is the most obvious way to load and unload containers to and from inland barges. The use of mechanical force to lift and replace containers creates a divers amount of possibilities. The first thing which comes to mind is a conventional crane. A conventional crane exists of a column and a boom (see figure 4.2). The boom is supported by wires from the top of the column. The height of these cranes is significant. This prevents these cranes from being implemented on inland barges. Another type of crane is more suitable for inland barges. Figure 4.3 shows a CBW-crane from Liebherr. The boom is not supported by wires from above, but by a cylinder from below, reducing the air draft significantly.

4.2 Conventional cargo crane



4.3 CADdrawing CBW crane from Liebherr.

These CBW can lift up to 35 ton at a maximum outreach of 38 meter. A CBW crane can handle up to 20 containers per hour (Waterwegen en Zeekanaal, 2005)

There are two examples of (inland) barges on which a CBW crane is installed onboard. The first is sailing in the Amsterdam region. It is the AMS-barge from Mercurius Shipping (See figure 4.4). This is an inland barge, designed to transport containers and has a capacity of 85 TEU. This vessel will set the benchmark for the developed concepts. The concept will be described in more detail further on in this report.

Figure 4.4 AMSBarge craneship

Another example of the use of a CBW-type crane is the *Port Feeder Barge*. This, 63 meter long, barge (see figure 4.5) was designed for the port of Hamburg (D) and has a capacity of 168 TEU. Its meaning was to centralize container flows from terminals to inland barges so that these inland barges would only have to visit the Port Feeder Barge when sailing in a main port. The time inland barges were in a port could be reduced significantly. The barge itself could only sail up to six knots, but given the long round trip time of inland barges, this would be sufficient. The port feeder barge has not been built yet. The economic viability of this concept can be questioned because it adds an expensive container move to the supply chain. The Port Feeder Barge is in fact the same as the AMSBarge, but without propulsion for higher speeds and the possibility of sleeping onboard.

Figure 4.5 Port Feeder Barge (Port Feeder Barge, 2006)

A third example of container handling by crane is the *Porthopper.* The Porthopper uses a different crane then the AMSBarge or the Port Feeder barge. The Porthopper is designed for small inland vessels and is able to transfer containers sideways. (see figure 4.6) An important aspect of this concept is the stabilization foot located on the quay to prevent the barge from heeling. This will result in high quayside pressures. Using this concept will only be possible if the quay is sufficiently strong. The crane is engineered in such a way that when the barge is sailing, air draft is limited. The crane is foldable. The rate of container transfers is unknown since this crane has never been built.

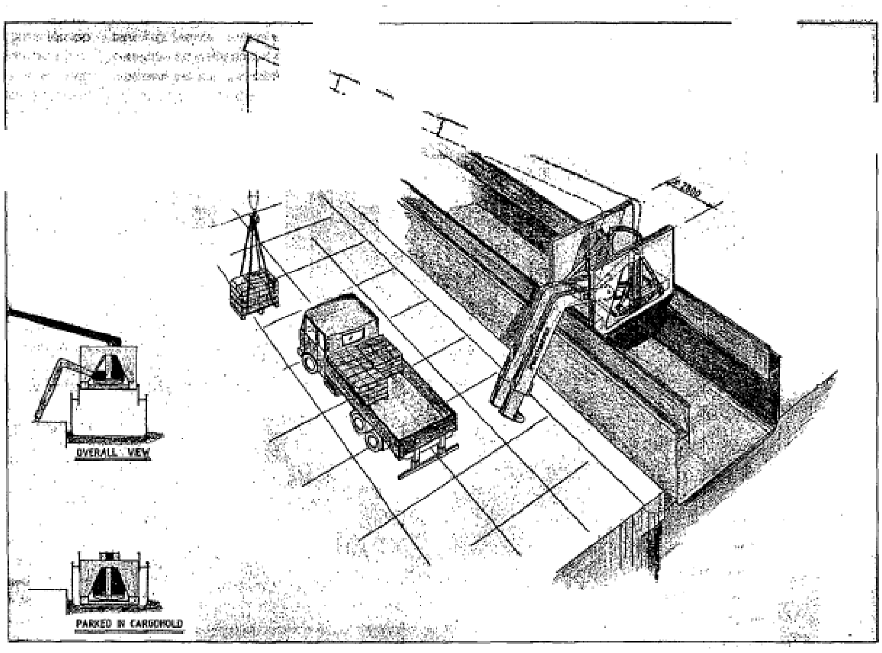
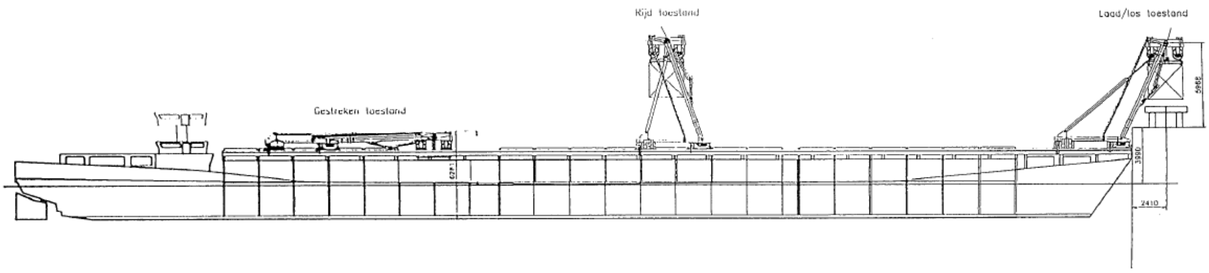


Figure 4.6 PortHopper (Schip Werf en Zee, 1999)

4.2.2 Lifting by gantry crane

When speaking about gantry cranes, people often refer to the very large ones found in sea ports which are used for loading and unloading of containers from ocean-going container vessels. These gantry cranes are much too big for inland vessels. It may however be possible to scale these gantry cranes to fit on inland barges.

An example of a system which is very much the same as a gantry crane is the “koploper”. (see 4.7). This system is capable of lifting 20 foot containers and transporting them in longitudinal direction. The Koploper can unload the containers by canting them forwards over the bow. This system has its pros and cons. It is not likely to have a high handling rate and its outreach is limited. It is not able to load containers sideways which limit the loading/unloading locations since there are very few quays suitable for this process. The koploper uses limited space onboard but is not really suited for larger volumes since its dimensions will increase considerably. The logistical system around the koploper is of great importance since the koploper is not able to offload 2 containers on the same spot. The containers will have to be removed instantly or the system comes to a standstill.



4.7 Koploper (Nuhn, 1998)

The absence of quays, suitable for the Koploper is a reason to develop a gantry crane which loads and unloads containers sideways. This “Side loader gantry crane” is capable of loading and unloading containers in a transverse direction (See figure 4.9 and figure 4.10). The outreach of the gantry crane is equal to the ships’ width. Dependent on the ships dimensions and class regulations, it may be necessary to install a contra weight. This weight limits the inclination, which is a result of the container being lifted outwards. The rail-mounted gantry crane is capable of loading and unloading containers over the entire length of the barge. The loading and unloading is only possible to one side of the barge.

An important feature of this gantry crane is the fact that it is foldable. Its sailing dimensions are significantly smaller than the offloading dimensions. It is possible to lower the gantry crane, by means of telescopic legs, on top of the third container layer. A loss in capacity is the result. This could be prevented if the gantry crane is lowered on for instance the fore or aft deck. The aft deck will probably not be accessible because of the wheelhouse. It can be questioned whether there is enough space on the fore deck. Figure 4.11 shows the gantry crane when folded.

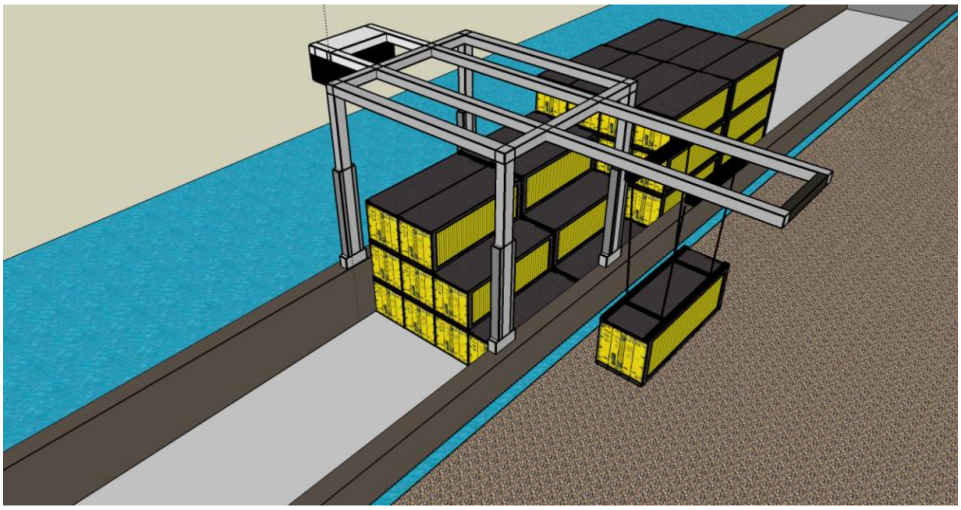


Figure 4.9 Side loader Gantry Crane in operation (1)

Figure 4.10 Side loader Gantry Crane in operation(2)

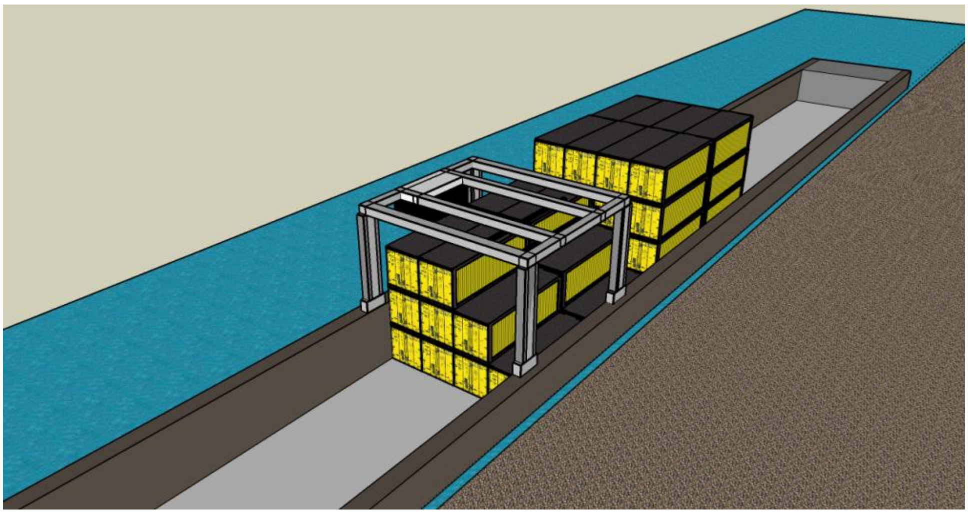


Figure 4.11 Side loader Gantry Crane in sailing condition (folded)

4.3 Rolling

Lifting containers demands a significant investment in equipment, space and weight. Rolling containers to shore could reduce the necessary investment in loading and unloading equipment. It is also possible to roll containers group wise to the quay. This could lead to an increase in container throughput. There is however a limiting problem. Rolling is only possible if the cargo is pulled towards the quay by means of a winch or as a result of gravity (and a small angle towards the quay). It is not possible to get containers ashore from the hold of the vessels without the usage of supplementary equipment.

4.3.1 Rollerbarge

The “Rollerbarge” is an example of rolling containers to and from the quay. Appendix 4.1 shows the working principle of the Rollerbarge. This concept has a lot of variants. But in general, some sort of lifting equipment lifts the containers from the hold and rolls them to the quay. (Pennings, 1997)

The challenge with the concept of rolling is the transition from ship to shore. This will have to be flat and smooth. If there is an edge between the barge and the quay, it is likely that the rolling will fail. During unloading, the trim has to be corrected actively. The investment in equipment is expected to be significant and quay pressures will be high.

4.3.2 Roll-on Roll-of

A familiar way to load and unload containers is the so-called *Ro-Ro,* Roll-on Roll-off. Containers are transported while being located on a chassis, an AGV (Automated Guided Vehicle) or any other type of rolling support. The transfer speed can become very high with Ro-Ro. The transfer speed will become a critical factor in the success of the barge (see chapter 5).

An example of a developed concept of Ro-Ro in the inland navigation sector is the IPSI project (Interface, 2006) Figure 4.12 gives an overview of the IPSI logistical system in a terminal. Ro-Ro can be successful if the transfer speed is sufficiently high with respect to the loss in capacity which is the result of transporting not solely containers, but also chassis.

It has to be considered as well that significant investments have to be done in dedicated equipment for loading and unloading of containers. One of the investments has to be done in a ramp. In case of multiple container layers, the technical demands for the ramp lead to increasing investments costs.

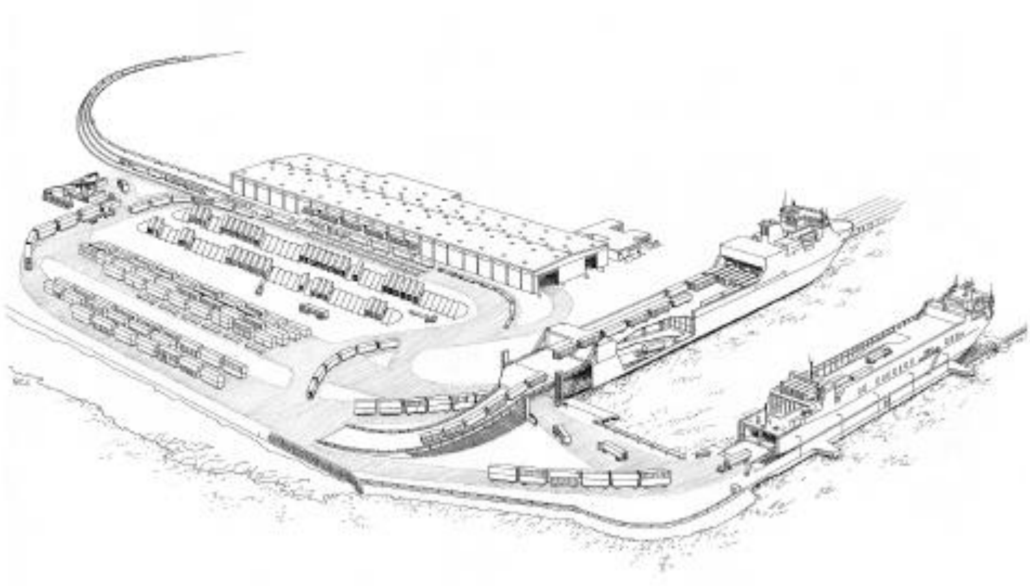


Figure 4.12 IPSI (Interface, 2006)

4.4 Preliminary equipment choice

The previously mentioned container handling equipment types represent a variety of ways to load and unload containers. A selection has to be made. It is very hard to quantify all parameters which were mentioned in the start of this chapter. Most of the parameters are unknown and not easily determined. Estimating the size and influence of all parameters would result in huge amounts of engineering.

The two most suitable equipment types can however be determined. Most concepts have a clear shortcoming compared to other concepts. It is therefore not necessary to quantify all parameters if a choice has to be made.

The Koplopers' most significant shortcomings are the low transfer rate, the small outreach and dependability on the logistical system. Loading and unloading containers in a longitudinal direction is unlikely to be successful.

The Port Hopper fails in one significant parameter. The stabilization foot requires significant investment in quay strength. The demanded investment in quays is a clear violation with the design philosophy of this thesis and the Port Hopper can therefore be cancelled from the list of potential equipment types.

The Rollerbarge is an unproven, relatively complicated system. Lifting containers to deck level is a necessity because otherwise the barge's capacity would be reduced significantly. The lifting equipment is complex, unproven and the influence of rolling on the behavior of the barge is not sufficiently researched.

The Side Loader Gantry Crane seems to be perfect, but its technological feasibility is questionable. Transferring a container in a transverse direction creates a very large bending moment in the structure of the gantry crane. The strength of the crane is a challenge since the structural solutions are by the operational demands from the barge. Appendix 4.2 shows a calculation of the strain in a beam with a bending moment of 300 tonm. This is the same moment a container would cause, when it is transferred 10 meter in the transverse direction. The beams dimensions are large, and its weight is estimated at 500 kg/m.

An important restriction to the crane is the limited air draft. This limits the possibilities of rerouting tensional forces from the *outreach beam* to other beams.

The resistance against this type of loading and unloading equipment is supported by (Heukelum, 1991) which states that a gantry crane is expensive and structural challenges are hard to overcome. The telescopic legs of the gantry crane are a challenge as well.

Two concepts remain. The conventional crane and the Ro-Ro concept are chosen as the two most suitable ways to load and unload containers from an inland barge. The technological feasibility of these concepts is of great importance in the selection process. These concepts have been implemented before as transport concepts.

This chapter has shown that there are many ways to load & unload containers from inland barges. It becomes clear that doing this without threatening the success of the barges from an economic and logistic point of view is a challenge. Most of the concepts encounter significant limitations and depend on shore facilities. The conventional crane concept is flexible and almost independent of shore and quay facilities. The Ro-Ro concept is chosen because it should be able to load & unload container at a very high transfer rate, a parameter which might become very important in the overall success of the developed barges.

These two concepts will be evaluated thoroughly in the following chapters from an economic and logistic point of view. Chosen either one of the concepts will result in a difference in transport price and logistic performance. These will be calculated and explained further on in this report.

5 Preliminary Cost and Capacity Calculation

An important parameter of an inland vessel is its transport capacity. A design should be optimized to transport as much as possible cargo at the lowest cost. It is only possible to start a design if the preferred amount of capacity is known. This chapter will create insight in the cost structure of the inland vessel and the influence of a variety of parameters on the cost level per transported container. The cost of loading and unloading containers at terminals and the cost of for instance passing the locks are not included in this calculation.

5.1 Model Description

The preliminary cost calculation is based on a report from NEA (NEA transportonderzoek, 2004) which describes the cost of inland shipping per hour as a function of the transported tonnage. The amount of transported containers can be calculated from this tonnage, given an estimated average weight of 14 ton per TEU.

5.1.1 Roundtrip time

A roundtrip is separated into a sailing part ($hours_{sailing}$) and a loading/unloading part ($hours_{wait}$). The duration of the sailing part is equal to twice the distance divided by the sailing speed. Passing a lock will take 30 minutes on average. It is estimated that mooring and unmooring will take 30 minutes as well. The total sailing time is equal to:

$$hours_{sailing} = \frac{2 * distance}{speed} + \frac{locks}{2} + amountofstops * 1 \quad (5.1)$$

The loading and unloading time is equal to the capacity of the vessel minus the capacity taken by the loading/unloading equipment multiplied with a factor four and the occupation rate, divided by the transfer rate. In formula-form:

$$hours_{wait} = \frac{(Capacity - equipementloss) * 4 * occup.degree}{transferrate} \quad (5.2)$$

5.1.2 Cost factors

The NEA report (NEA transportonderzoek, 2004) shows four categories of cost. The first one is material cost, the second one is employment cost, the third is fuel cost and the fourth category is maintenance (and repair).

Material Cost

The material cost is in fact the cost of capital. It is the sum of insurance cost, depreciation, interest and the fixed part of maintenance (half is estimated as variable). The depreciation is dependent on the insured value of the vessel, the residual value after depreciation and the length of the depreciation period. The residual value is a fixed percentage of the insured value. The insurance cost is a fixed percentage of the insured value as well.

The interest costs are dependent on the insured value, the residual value after depreciation of the vessel, the amount of debt capital, the amount invested by the owner and the corresponding interest percentages. The formula for interest costs is:

$$Interestcost = \frac{(insur.value + Resid.value)}{2} * (invest\ equity * inter.rate + debt * inter.rate) \quad (5.3)$$

Employment cost
The employment costs are based on the Collective Labour Agreement from 2003-2005, corrected for the increase in wage until 2007. Calculating employment costs is difficult as they are influenced by many variables. The wages are based on working 40 hours per week, and ten hours per day. Working more means getting paid overtime at a different wage per hour. Working on Saturday is paid differently than normal days, overtime on Saturday is paid different then overtime on Monday. Working on a 14 hour schedule per day is paid differently than an 18 or 24 hour schedule.

The added costs for employers are not known. The level of insurances, taxes and payments for for instance pensions are unknown and dependent on country of registration. The calculations of the costs for employment are not made by the author of this report and therefore solely extracted from the previously mentioned source.

Fuel Costs
The fuel costs are a function of the engine power (and thus the sailing speed), the fuel usage per kWh and the price of the fuel per ton. The NEA report estimated the fuel price in 2003 at 30 eurocents per liter. The fuel index for the period 2003-2007 is 1.7. The price of MDO was in the range 500-550 euro's per ton in 2007. The index is therefore correct. It is possible to calculate engine powers from the fuel costs in order to check whether the NEA report has used correct figures. A quick check confirms the fuel costs as calculated by NEA.

Maintenance
This cost item is the total of repair and maintenance done to the vessel in one year. The maintenance post is partly fixed and partly variable. The fixed part is represented in the material costs. That is expected to be half of the total maintenance post. Divide the residual by the amount of sailing hours per year, and the maintenance cost per hour is known.

5.1.3 Actual Cost figures

The following table shows the costs, divided into the previously mentioned categories, of inland shipping per hour, when sailing with freight.

The cost structure of an inland barge is slightly different when loading and unloading containers at a quayside. The cost structure consists of material costs, employment costs and equipment costs.

Table 5.1 originates from a 2003 source and is therefore outdated. These numbers can be scaled to 2007 values, using figure 5.1. It is possible to scale the costs to 2007. Since it was not possible to get indices for 2008 at the start of this thesis and since the influence of the economic breakdown on the inland navigation sector is hard to estimate, the 2007 figures are used in this thesis.

DWT	TEU	Material Cost	Employment cost	Fuel	Maint.	Total/Cont
ton	(-)	euro/hour	euro/hour	euro/hour	euro/hour	euro/hour
250	18	4,18	27,16	7,96	2,91	2,35
500	36	9,11	29,22	14,14	3,43	1,55
750	54	15,67	31,29	20,32	3,92	1,32
1000	72	23,51	34,21	26,50	4,38	1,23
1250	90	31,95	39,07	32,68	4,81	1,21
1500	108	38,96	43,92	38,86	5,21	1,18
1750	125	47,15	48,13	45,04	5,59	1,17
2000	143	55,77	52,26	51,22	5,95	1,16
2250	160	64,47	56,39	57,40	6,29	1,15
2500	180	72,18	60,52	63,58	6,61	1,13
2750	200	78,55	62,70	59,76	6,92	1,09
3000	215	83,30	64,88	75,94	7,21	1,08
3250	235	86,16	67,06	82,12	7,48	1,03
3500	250	86,96	69,24	88,30	7,75	1,01

Table 5.1 Cost of inland shipping per hour 2003 (NEA transportonderzoek, 2004)

Indices	2003	2004	2005	2006	2007
Fuel costs	84	100	130	145	148
Personnel costs	98	100	101	103	105
Other costs	100	100	100	132	170
General year index for bulk sector	96	100	106,4	123,0	139,6

Figure 5.1 Indices for inland shipping costs (derived from: (Centrale Commissie voor deRijnvaart, 2008)

The Material- and maintenance costs are both scaled with a factor 1.7 which originates from “other costs” (nl: “overige kosten”).

Using these indices, table 5.1 becomes table 5.2:

DWT	TEU	Material Cost	Employment cost	Fuel	Maint.	Total/Cont
ton	(-)	euro/hour	euro/hour	euro/hour	euro/hour	euro/hour
250	18	7,11	29,10	14,02	4,95	3,07
500	36	15,49	31,31	24,91	5,83	2,15
750	54	26,64	33,53	35,80	6,66	1,90
1000	72	39,97	36,65	46,69	7,45	1,82
1250	90	54,32	41,86	57,58	8,18	1,80
1500	108	66,23	47,06	68,47	8,86	1,76
1750	125	80,16	51,57	79,36	9,50	1,76
2000	143	94,81	55,99	90,24	10,12	1,76
2250	160	109,60	60,42	101,13	10,69	1,76
2500	180	122,71	64,84	112,02	11,24	1,73
2750	200	133,54	67,18	105,29	11,76	1,59
3000	215	141,61	69,51	133,80	12,26	1,66
3250	235	146,47	71,85	144,69	12,72	1,60
3500	250	147,83	74,19	155,58	13,18	1,56

Table 5.2 Cost of inland shipping per hour 2007

The NEA tables are derived from a database filled with data mainly originating from the existing inland shipping fleet. It is remarkable that the employment costs vary with every increase in deadweight tonnage. It is unlikely that for instance a barge with 18 TEU will have more crew than a barge with 36 TEU.

Crewing regulations mainly depend on the length of the barge. The minimal amount of crew is specified for three types of inland barges. Table 5.3 specifies these categories and shows the corresponding costs. The specification into category A1/A2/B is equal to sailing 14/18/24 hours per day. The category S1/S2 specifies whether a bow thruster or hydraulic mooring winches are installed.

	A1		**A2**		**B**	
	S1	**S2**	**S1**	**S2**	**S1**	**S2**
L<=70 m	26.88	26.88	44.60	44.60	65.98	58.47
70< L <= 86 m	29.98	32.23	52.46	52.41	74.43	66.90
L> 86 m	41.81	36.28	67.89	60.35	114.24	87.30
> 2500 T of cargo	42.14	36.61	68.79	61.26	115.15	88.20

Table 5.3 Employment Costs (NEA transportonderzoek, 2004)

The following formula is used to create a connection between the deadweight and the length of the barge. Using this formula creates the possibility to calculate the employment cost as a function of the transport capacity. (NEA transportonderzoek, 2004)

$$L(m) = 0.01 * \sqrt[3]{-1.061 * 10^{11} + (DWT * 4.865 * 10^{8})} \qquad (5.4)$$

L is the length in meter. DWT (deadweight tonnage) is the maximum weight of the transported freight.

Table 5.2 is used to create polynomial functions. Plotting for instance the material costs in *Microsoft Excel* creates the possibility to calculate (or actually let Excel calculate) a polynomial function. To create the most accurate fit, all polynomials are of the power five or six. The choice for such a high order results in the fact that it is not possible to extrapolate outside the boundaries of table 5.2. The behavior of the polynomial is not according to the trend of the original values. Figure 5.2 shows this.

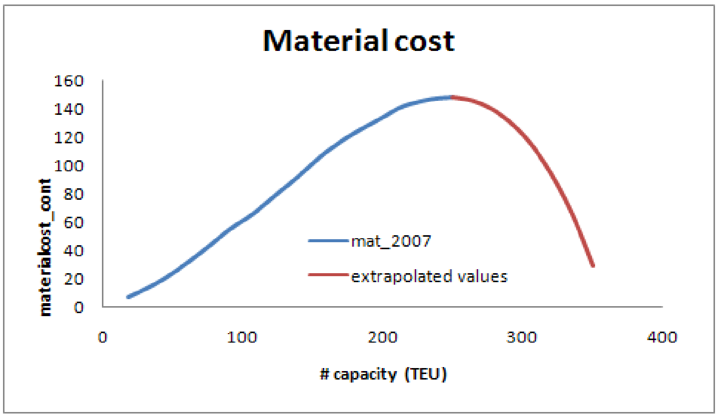


Figure 5.2 extrapolated material cost

It is therefore not possible to calculate with capacities over 250 TEU. This may seem a remarkable restriction and unreasonable limitation to this thesis. The size of the inland barge is in fact limited to 135*12.5 meter (lock dimensions). It could be possible to increase the size of the barge, but increases the risk of congestion at locks since the amount of locks with a length over 135 meters is limited. The operating range of the barge would be limited to the Albert canal as well.

An example of an inland barge of 135m*11.45m (L*B) is the Camaro IV, transporting 314 containers in 5 layers. The maximum deadweight is 3255 ton (weblog, 2008). The maximum draught of the Camaro IV is 4.55 which exceed the maximum allowed draught in the Albert canal (3.4 meter). This reduces the amount of containers the Camaro IV can transport on the Albert canal.

Figure 5.3 Camaro-IV

Given for instance an inland barge with the dimensions 135*11.45*3.5 (L*B*T) and a block coefficient of 0.85, the displacement is 4598 m^3. This value minus the estimated lightweight of 1000 ton and divided by the average container weight results in the maximum amount of containers which can be transported to be 250 TEU. The range of 0-250 TEU for the polynomials can therefore be called sufficient.

5.1.4 Cost model Input

An excel sheet was built to calculate the cost of container transport. The input of the sheet is shown in figure 5.4

concept nr	1	2	3
speed (km/h)	12	12	12
route	1	1	1
lock time (hr)	0,5	0,5	0,5
# stops stoptime=1 hour	3	3	3
distance (km)	350	350	350
amount locks	12	12	12
equipment type	3	3	3
transfer rate (teu/hr)	34	34	34
loss TEU	40	40	40
price_equipment (€)	1400000	1400000	1400000
capacity (TEU)	50	60	70
Occupation degree	0,7	0,7	0,7
5/6 days/week	5	5	5
14/18/24 hours	14,00	14,00	14,00

Figure 5.4 excel sheet cost_cont input example

The speed could be a variable, but is chosen as a fixed number. The speed of the barges is equal to the maximum speed, 12 km/hour.

Three routes have been specified. These routes have been chosen because they represent the most important freight flows on the Albert canal. All routes start in Antwerp since Antwerp is either the origin or the destination of almost all freight on the Albert canal.

route		distance	locks
1	Antwerp-Lanaken-Antwerp	230	12
2	Antwerp-Meerhout-Antwerp	100	6
3	Antwerp-Genk-Antwerp	170	12

Figure 5.5 transport routes

The amount of stops at terminals influences the overall roundtrip time because mooring and unmooring is estimated to take one hour. This variable makes it possible to create insight in the influence of an increase in visited terminals or companies on the overall roundtrip time and cost per transported container.

The influence of different equipment types can be calculated as well. Figure 5.6 shows the three equipment types. The transfer rate represents the amount of containers which can be transferred from ship to shore and vice versa per hour.

equipment		transfer rate	Loss TEU	Price
1	conventional crane	17	20	700000
2	gantry crane	25	20	1000000
3	2 conventional cranes	34	40	1400000

Figure 5.6 Equipment Types

The “Loss TEU” indicates the loss in capacity of the vessel as a result of the installed equipment. The variable “capacity” represents the vessels capacity without the loss of the installed equipment. It is the input variable for various cost polynomials.

5.1.5 Cost model output

Figure 5.7 shows the outcome of the cost model.

triptime (hours)	38,99	39,81	40,64		wait_rest_hour	€ 52,26
triptime (days)	2,79	2,84	2,90		tot_wait_hour	€ 79,14
amount trips/wk	1,80	1,76	1,72		hours_wait	€ 1,18
length	61,66	67,13	71,83		hours_nonwait	€ 38,17
Arb_cost	€ 26,88	€ 26,88	€ 32,23		equip_cost_hour	€ 58,00
rest_cost_hour	€ 63,69	€ 76,83	€ 90,45		equip_cost_trip	€ 68,24
mat_cost_14 hours	€ 24,41	€ 31,00	€ 38,01		cost_trip	€ 3.618,05
mat_cost_hour	€ 24,41	€ 31,00	€ 38,01		cost_cont	€ 258,43
tot_cost_hour	€ 90,57	€ 103,72	€ 122,67		total_amount_teu	€ 1.256,73
wait_arb	€ 26,88	€ 26,88	€ 32,23			

Figure 5.7 output cost model example

The first three outcome results need no further explanation. The length is the result of formula 5.4. “Arb_cost” is the cost of employment. “rest_cost_hour”, “mat_cost_14 hours”, “mat_cost_hour” and “wait_rest_hour” are the result of calculated polynomials.

The equipment will be depreciated to zero in ten years time, at an interest rate of 5%. The repair and maintenance of the equipment is assumed to be 2% of the purchase price. The most important outcomes are "cost_cont" and "total_amount_teu". The first one is the actual cost per transported container; the second one represents the total amount of containers which will be transported by the barge per year, given the assumptions done in the input. This is important since this number will tell something about the market share the vessel will take.

5.2 Calculation model results

The outcome of the model will be shown and evaluated in this paragraph. First, the outcome of the model with respect to conventional loading/unloading will be shown. Roll-on Roll-off will be evaluated afterwards.

5.2.1 Conventional loading/unloading

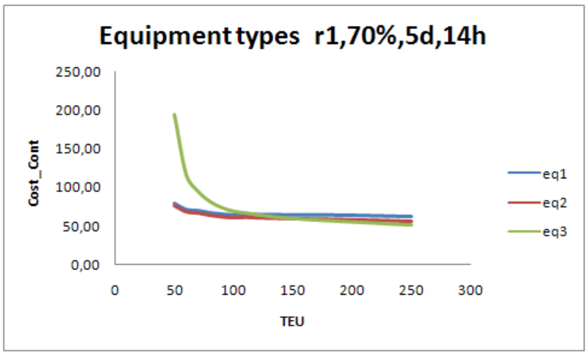


Figure 5.7 equipment types

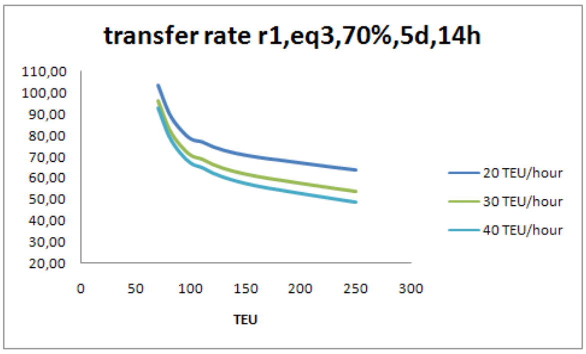


Figure 5.8 transfer rate

The first figure (5.7) shows the cost per transported container as a function of the total transport capacity. The title of the figure describes the settings of the main variables. Figure 5.7 represents the cost per transported container on Route 1 (r1), the occupation rate is 70%, the barge sails 5 days a week (5d), 14 hours per day (14h).

The most important conclusion from this paragraph is the fact that equipment type three (two conventional cranes) can only be preferred with respect to the other equipment types if the transport capacity is over 150 TEU. In the lower capacity range, the influence of the loss in capacity becomes increasingly important. The price of the installed equipment has a very limited influence on the total transport cost and becomes even less when the capacity increases. The scale advantage of equipment type one and two are close to zero. While using equipment type three, it seems profitable to increase the total transport capacity.

The second figure (5.8) shows the influence of an increase in transfer rate on the cost per transported container. The transfer rate of equipment type three has been varied. The sharp rise in container costs in the smaller capacity range can be explained by the fact that equipment type three reduces the barges capacity by 40 TEU. This becomes an increasingly large percentage of the total in the lower TEU range. The fixed cost of the vessel (for instance material costs) is distributed amongst a small amount of TEU.

In figure 5.8, a significant scale advantage can be observed. The cost per container decreases considerably as the capacity increases. The higher the transfer rate, the steeper the decrease of the container cost.

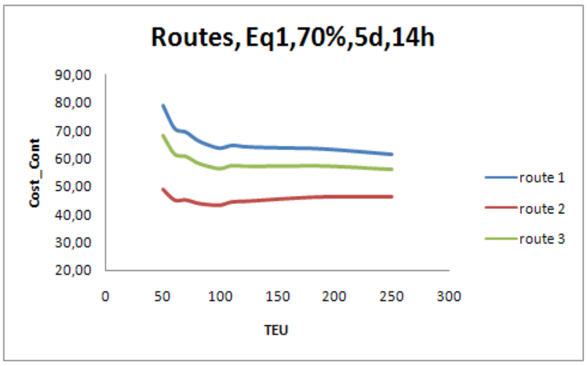


Figure 5.9 Routes, equipment 1

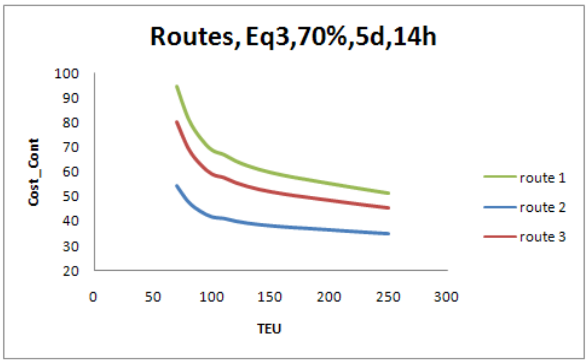


Figure 5.10 Routes: equipment 3

The influence of the transfer rate becomes increasingly clear from figure 5.9 and 5.10. These two figures show the cost levels of an inland barge with varying capacities. In fact, figure 5.9 gives no reason for an increase in scale. There is simply no scale advantage. There might be a small scale advantage if the transport distance increases considerably.

An important factor is the ratio between sailing time and loading/unloading time. Reducing loading/unloading time reduces the price per container since the cost per container is equal to the sum of the cost of sailing the container to its destination and the cost while loading/unloading.

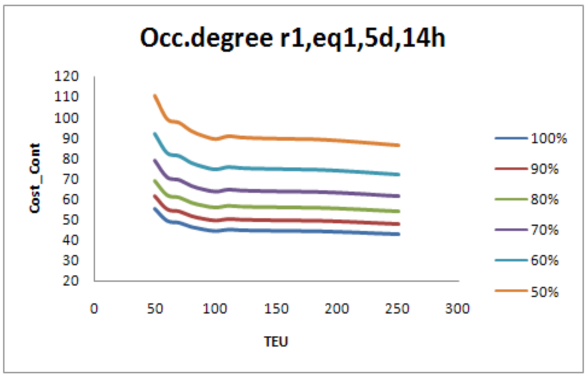


Figure 5.11 Routes, occ.rate eq1

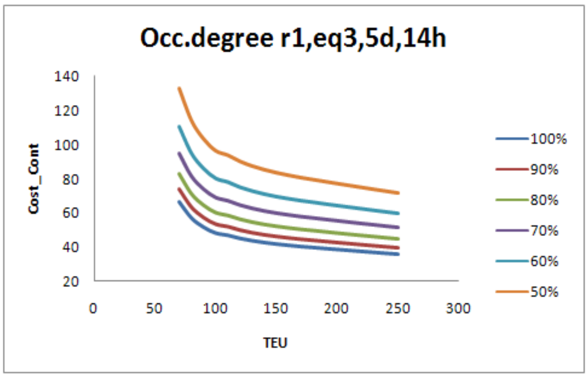


Figure 5.12 Routes, occ.rate eq3

The occupation ratio is the rate between the capacity of the vessel available for container transport and the actual amount of transported containers. Figure 5.11 and 5.12 show the influence of the occupation rate on the cost per transported container on route 1. These two figures show that the cost per transported container rises exponentially if the occupation rate decreases. The fixed and variable costs of sailing a barge are divided amongst a decreasing amount of containers. In reality, the fuel costs are dependent on the occupation rate. This effect is not incorporated in the model. The trend of the costs at different occupation rate should be a bit more convergent.

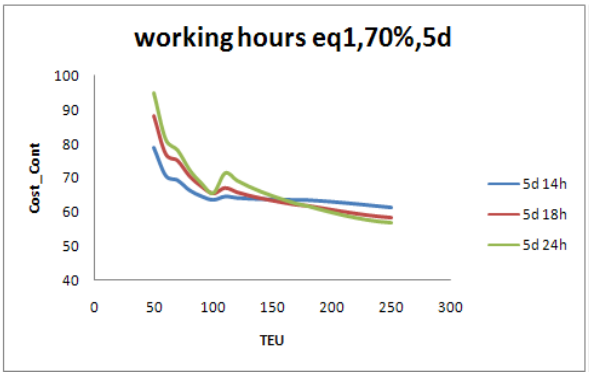


Figure 5.13 Working schedule eq1

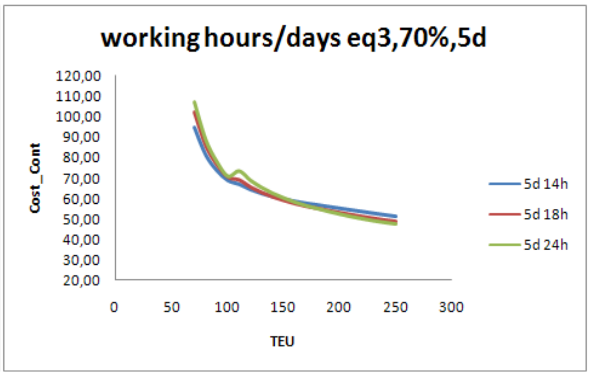


Figure 5.14 Working schedule eq3

Figure 5.13 and 5.14 show the differences in cost per transported container, when the barge is sailing a daytrip, semi-continuous of full-continuous. The employment cost per hour rises significantly when a barge sails for instance 24 hours per day instead of 14 hours. This is the result of an increasing amount of personnel onboard as well as a higher wage per hour.

It could however be interesting to sail 24 hours per day because the total container throughput increases significantly. This effect can be observed most clearly in figure 5.13. Sailing 24 hours per day could become viable if the transport capacity is over 200 containers. It can however be questioned whether terminal locations will be able to handle containers 24 hours per day. The market share of the barge will increase significantly as well. It can be questioned whether a new concept is able to take such a significant market share from the start. Sailing 24 hours per day, 6 days per week will however result in the lowest cost per transported container.

5.3 Roll-on Roll-of

It is expected that the loss in capacity will have a great influence on the price per transported container. The transfer speed should make up for the loss in capacity. The capacity is estimated at 56 TEU (or equivalently 28 FEU or trucks) per container layer. Two or three layers of trucks should be possible, given the air draft restriction. The RoRo system is compared with a barge that loads and unloads containers by means of two conventional cranes. (Equipment type 3). The occupation rate is set at 70%.

Figure 5.15 shows the influence of an increase in transfer speed of the RoRo concept on the cost per transported container. The cost structure of a vessel with a capacity of 250 TEU is chosen for the RoRo barge with a capacity of 112 TEU. The investment is expected to be one million euros.

Figure 5.16 clearly shows that the loss in capacity is directly responsible for an increase in cost per container. If the capacity increases to 168 TEU (three layers), the RoRo system results in a lower price per container if the transfer speed increases to at least 120 TEU/hour.

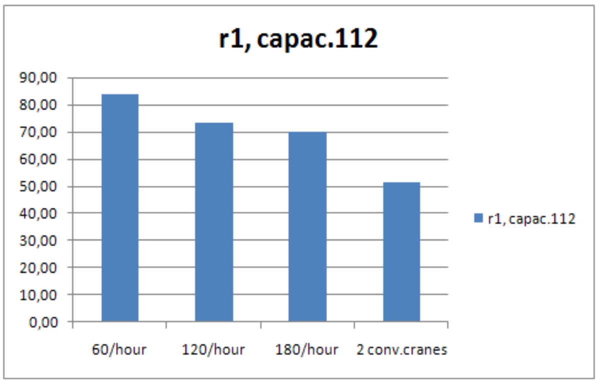


Figure 5.15 transfer speed RoRo

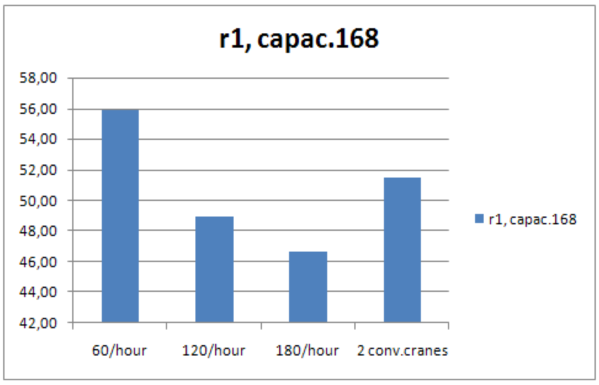


Figure 5.16 transfer speed

If the necessary investment for RoRo transport increases to for instance three million, figure 5.17 is the result.

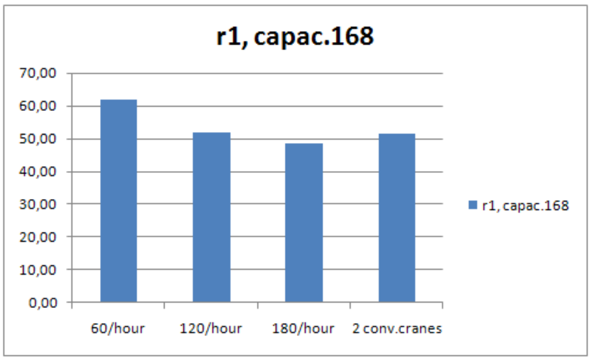


Figure 5.17 increased investment RoRo

The cost per container increases considerably as a result of the increased investment. The price per transported container is very sensitive to either the transfer speed as well as the necessary investment.

5.4 Conclusion

The cost model was developed to answer questions about transport capacities and the influence of different loading and unloading systems. The cost model has created some interesting insights in the influence of a variety of parameters on the cost level of container transport on the Albert canal.

5.4.1 Equipment

The influence of the type of equipment on the capacity is significant. As previously mentioned, there are no economic scale efficiencies above 100 TEU if one conventional crane is installed. Such a barge does already exist and is called the AMSBarge.

Installing two conventional cranes increases the transfer speed and decreases the waiting time at quays. This is of great importance, given the fact that the cost of loading and unloading is responsible for a significant part of the total cost per transported container.

The influence of the price of loading and unloading equipment on the cost per container is mainly dependent on the total amount of transported containers per year. In RoRo transport, the necessary investment in a ramp and loading/unloading equipment are serious threats to the economic viability.

This thesis aims at transporting large amounts of containers. It can be concluded that installing two conventional cranes will contribute most to the economic competitiveness of an autonomous inland barge.

5.4.2 Capacity

The lowest costs per transported container can be achieved by transporting as much containers as possible. Given the fact that lock sizes limit the physical dimensions of an inland barge, the maximum dimensions have been chosen as 135*11.5 meter. A capacity of 250 TEU should be realizable. The design will have to be optimized with respect to the containers capacity. The location of the conventional cranes can be varied, and the loss in capacity will have to be minimized.

6 Basic Design inland barge

This chapter describes the development of the autonomous loading and unloading inland barge. The design is limited by the maximum dimensions as defined in the previous chapter. The maximum Length (L_{oa}) is 135 meter. The maximum breadth (B) is 11,45 meter. The maximum draught (T_{max}) is limited by regulations to 3,5 meter even though the canals dimensions would allow vessels with a maximum draught of 5 meter to sail on its waters.

6.1 Design draught

An important decision has to be made in advance of the actual design of the barge. What will be the design draught of the vessel? The barge occupation rate will not always (or probably almost never) be a 100%. The design draught is important with respect to the propeller diameter (P_d) and the corresponding propulsion efficiency. Preferably, the P_d is as large as possible, resulting in low propeller loads and a higher efficiency (actuator disk theory). If the vessel would be designed for T_{max}, P_d will be about 3,3 meter. If the barge is not loaded to T_{max} the propeller might become a surface piercing propeller and this will have a significant influence on the propellers efficiency.

Adjusting the trim of the barge is possible by positioning the heavy containers behind the longitudinal center of buoyancy and light ones in front of it. It is possible to use ballast water to trim the barge and increase the draught at the aft of the barge, but using ballast water will only increase the weight of the barge and thus increase the cost of transport without adding any revenues. An assumption has to be made with respect to the expected occupation rate of the barge. The design occupation rate is chosen as 80%.

The displacement of the vessel is equal to the sum of the light- and deadweight (LW and DWT) of the barge. As a first assumption, the lightweight of the vessel is estimated to be 900 tons (Bureau Veritas (B), 2009), the CBW cranes weigh 57 tons each (see specification appendix 6.1) and the average weight of a container is estimated to be 15 tons.

The barge's capacity for the transport of containers is calculated at 241 TEU. Figure 6.1 shows a schematic top view of the barge. The length of the barge (Lwl) is 135 meter. The position of the collision bulkhead is defined by regulation to be at least 4% from the forward peak. (Bureau Veritas (A), 2009). The position of the machinery space bulkhead is preferably positioned as far aft as possible.

A preliminary shape has been defined, as shown in figure 6.2, as the shape of the aft ship. The position of the aft bulkhead is at least 7 times the propeller diameter away from the stern. The estimated length needed for the bowthruster is 2 meter. The midship section's length is further reduced by the presence of two conventional cranes. Based on appendix 6.1, it is estimated that at least 4 meters are needed to install the cranes. Estimating Pd to be 2.50 meter, the remaining length for container transport is $135 - (7 * 2.50) - (2 * 4) - (0.04 * 135 + 2) = 102.1\ meter$. Given the fact that a TEU has a lenght 6.30 meter, this 102.1 meter is just sufficient to store 16 containers in longitudinal direction. In transverse direction, the containers will be stored 4 wide and 4 high.

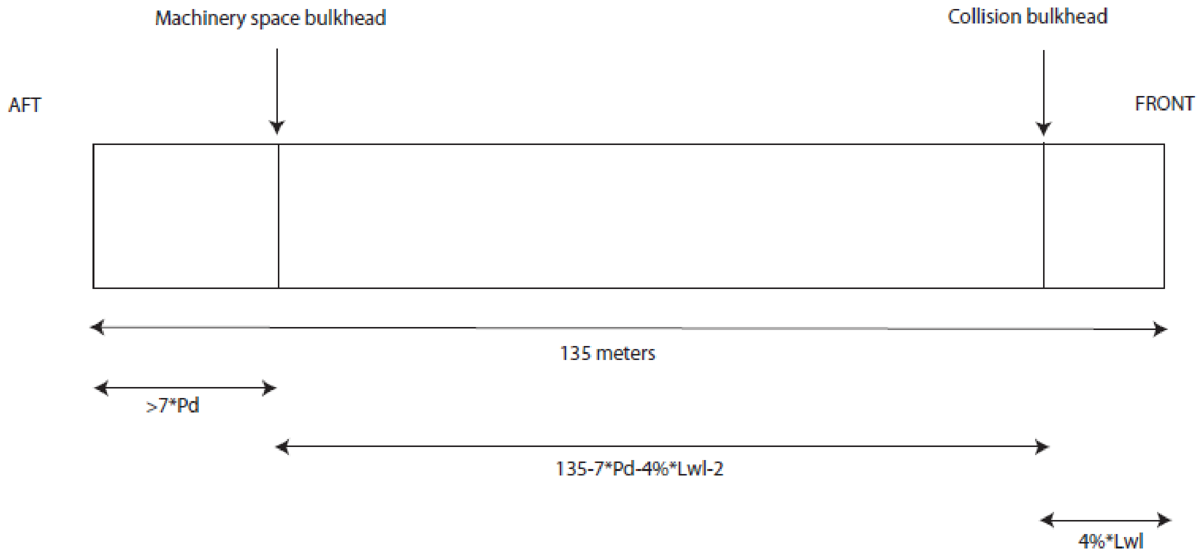


Figure 6.1 schematic topview barge

The capacity of the barge is further reduced by the presence of the two conventional cranes. From the specifications of the crane, it is estimated that a crane reduces the capacity with seven TEU. The capacity of the Barge will therefore be 242 TEU. 80% of this is 192 TEU. The sum of the estimated lightweight, 192 TEU and the two cranes is 4,000 tons.

The program Delftship (Delftship, 2008) has been used to estimate the design draught of the barge. Figures 6.2 and 6.3 show the shape of the aft and the front of the barge. These shapes have not been optimized in this case but it is expected that adapting these shapes will result in minor draught changes. These shapes have been based on a comparison of viscous drag of various shapes by Van Terwisga (Van Terwisga (a), 1989)

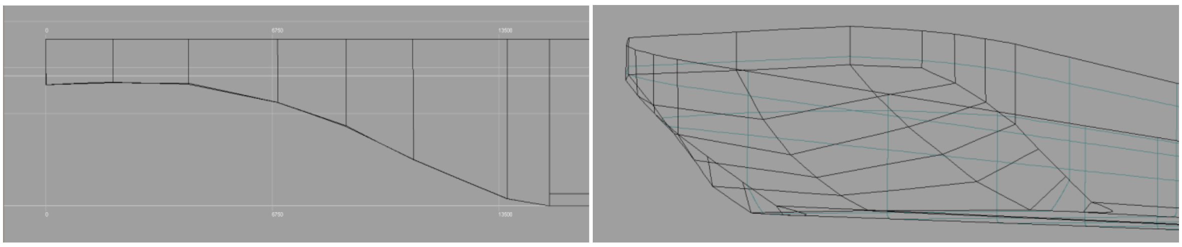


Figure 6.2 and 6.3, preliminary shape aft and front of barge

Appendix 6.3 shows the outcome of the hydrostatic calculation *Delftship* has carried out. In fact it shows the displacement with increasing draught. The Delftship calculation shows a design draft of 2,90 meter at 4,000 cubic meter displacement.

6.2 Resistance

Calculating the resistance of the barge is of great importance for the propeller calculation. This paragraph calculates the resistance of the barge, using a variety of methods and compares the outcome of the methods.

6.2.1 Resistance methods

The questions arises which method should be used when calculating the resistance of the barge. A variety of methods are available of which three will be used and compared in this chapter. Appendix 6.3 (Van Terwisga (a), 1989) gives an overview of a part of developed methods in the past. A remark has to be made because the methods from Van Terwisga (Van Terwisga (b), 1990) and from Bolt (Bolt, 2003) are not mentioned in this overview. Appendix 6.3 shows the constraints in which the calculations are valid. Remarkable is the fact the L/B ratio (length/width) range is mostly limited to a maximum of 6, whereas the designed inland barge has an L/B ratio is about 12. It can be therefore be questioned whether these calculation methods will give valid results.

The methods of Van Terwisga, Bolt and Holtrop & Mennen have been chosen to calculate the resistance of the barge. The Holtrop & Mennen's method is chosen because it should be able to calculate the resistance of vessels with a higher L/B ratio. The outcome of the three methods will be compared after calculating the resistance of the barge which each one of these three methods.

6.2.1.1 Van Terwisga Method

This method (Van Terwisga (b), 1990) is based on statistics from a variety of tests done within the MARIN. A regression analysis has been done on resistance tests of inland barges. The influence of a variety of parameters has been incorporated in the outcome of the regression analysis. Van Terwisga's research resulted in an empirical formula for the resistance of inland barges.

$$R_t = R_f + R_{tr} + R_w + R_{app} + R_{all} \tag{6.1}$$

R_f is the frictional resistance of an equivalent flat plate (ITTC-1957 frictional coefficients). The formule for R_f is:

$$R_f = \frac{0.5\rho * V_s^2 * S * 0.075}{(\log Rn - 2)^2} \tag{6.2}$$

$$R_n = \frac{V * L}{\nu} \tag{6.3}$$

The list of used abbreviations explains the variables used in the formulas.

R_{tr} is the part of the total resistance which is caused by the transom area below the waterline.

$$R_{tr} = 0.5 * \rho * V_s^2 * Atr * C_{d\text{-}tr} \tag{6.4}$$

$C_{d\text{-}tr}$ is a coefficient which follows from the regression analysis.

$$C_{d\text{-}tr} = 0.213 * \cos(\propto_{st}) \tag{6.5}$$

R_w is the wave resistance. Given a low Froude number and a high L/B ratio; the wave system is limited to just a bow wave. The influence of B is assumed to be significant. The *Van*

Terwisga method therefore decides to calculate the wave resistance with a Froude number based on the width of the barge.

$$R_{\mathrm{w}} = Q * \mathrm{F_{nB}}^6 * \rho * B^2 * T \tag{6.6}$$

$$Q = 0.18367 * (1 - C_{\mathrm{p}})^{-0.32144} * \left(\frac{B}{L}\right)^{0.562} * \left(\frac{B}{T}\right)^{0.22314} * \left(\frac{L}{L_{\mathrm{entr}}}\right)^{0.673} 2 \tag{6.7}$$

$$\mathrm{F_{nB}} = \frac{\mathrm{V_s}}{\sqrt{gB}} \tag{6.8}$$

R_{vp} is the viscous pressure drag of the barge. The formula for Rvp is:

$$R_{\mathrm{vp}} = P * \rho * \mathrm{V_s}^2 * B * T \tag{6.9}$$

$$P = 0.11712 * \left(\frac{T}{L}\right)^{0.78203} * (1.05 - Cpst)^{-1.0366} * (0.02 + 0.95 * \frac{\mathrm{H_{VA}}}{\mathrm{T_A}})\text{^}0.21336 \tag{6.10}$$

$$H_{\mathrm{VA}} = T_{\mathrm{A}} - H_{\mathrm{tr}} - R_{\mathrm{st}} * (1 - \cos(\alpha_{\mathrm{c}})) - (L_{\mathrm{c}} - R_{\mathrm{st}} * \sin(\alpha_{\mathrm{c}})) * \tan(\alpha_{\mathrm{c}}) \tag{6.11}$$

$$\alpha_{\mathrm{c}} = 14 * \sqrt{\frac{R_{\mathrm{st}}}{T_{\mathrm{A}}}} * \frac{\pi}{180} \tag{6.12}$$

R_{all} is the correction for the resistance of the barge from model to full scale. This is necessary since the regression model is based on model scale tests. The formula is:

$$R_{\mathrm{all}} = 0.5*\rho*\mathrm{S}*\mathrm{V_s}^2 * C_{\mathrm{a}} \tag{6.13}$$

The last part is the resistance caused by appendages (R_{app}) like the rudder. The formula can be found in chapter 6.2.3, which describes Holtrop & Mennen's method.

6.2.1.2 The Bolt Method

The resistance calculation method is based on "average" main dimensions of inland barges. The input variables of this method are therefore simple and few if compared to for instance the Van Terwisga method. The total resistance is equal to the sum of the frictional resistance, the pressure (wave) resistance and the resistance caused by shallow waters. The shallow water part will not be included in the comparison of the three prediction methods since the Van Terwisga method does not include such a resistance part.

$$Rt = Rf + Rp + Rs \tag{6.14}$$

The frictional resistance is based on the frictional coefficients as defined by the International Towing Tank Conference in 1957:

$$R_{\mathrm{f}} = \frac{0.5\rho*\mathrm{V_s}^2 * S * 0.075}{(\log Rn - 2)^2} \tag{6.15}$$

The wetted surface is estimated by using the following formula:

$$S = LB + 2LT \tag{6.16}$$

Formula 6.15 and 6.16 can be combined into:

$$R_f = 37.5 * (\log(V_s * L_{oa}) + 4)^{-2} * V_s^2 * S \tag{6.17}$$

In fact, the wetted surface is slightly larger than assumed in the formula 6.16. Bolt expects the frictional resistance to be significantly larger than the formula above because of appendages and roughness on the barges outer skin. A factor 1.4 is added to the frictional resistance. Van Terwisga does not add such a factor to the frictional resistance. R_f becomes:

$$Rf = 53 * (\log(V_s * L_{oa}) + 4)^{-2} * (LB + 2LT) * V_s^2 \tag{6.18}$$

The pressure resistance, R_p, is expected to be proportional with the hydrodynamic pressure.

$$R_p = C_p * 0.5 * \rho * V_s^2 * A_m \tag{6.19}$$

C_p is the pressure coefficient and largely dependent on the Froude number of the barge. Within the speed range of inland barge, C_p is assumed by Bolt to be constant. C_p is estimated to be 0.15.

As previously mentioned, the shallow water resistance will not be included in the comparison between the resistance prediction methods. It will be given here since it is a part of the Bolt Method.

$$R_z = C_z * \rho * g * z * B * T \tag{6.20}$$

C_z is a coefficient for the added resistance which is a result of the shallow water. It is assumed to be 0.2. Bolt’s method for shallow water resistance is based on the fact that the water level is reduced by the presence of the inland barge. The limited area of the river, through which the barge is sailing results in a higher water flow around the barge. In fact, the speed of the water around the barge is higher than the speed of the barge itself. The speed of the flow can be calculated by:

$$u = \frac{A_m/A_c}{1 - A_m/A_c - Fnh^2} * V_s \tag{6.21}$$

$$Fnh = \frac{V_s}{\sqrt{gh}} \tag{6.22}$$

The frictional resistance will therefore not be calculated with V_s, but with u. The reduction of the water level, z, can be calculated by:

$$z = \frac{A_m/A_c}{1 - A_m/A_c - Fnh^2} * Fnh^2 * h \tag{6.23}$$

It becomes clear that the ratio between de transverse area of the midship section and the transverse area of the river is of great importance.

The resistance of the barge in shallow water is:

$$R_t = 53 * (\log(V_s * L_{oa}) + 4)^{-2} * (LB + 2LT) * u^2 + C_p * 0.5 * \rho * V_s^2 * A_m + C_z * \rho g z * B * T \qquad (6.24)$$

6.2.1.3 Holtrop & Mennen Method

The Holtrop & Mennen method (Holtrop, J, Mennen, GGJ, 1982) is based on a regression analysis of model data as well as on full scale tests. The first aim of this prediction method was to improve "power prediction for high-block ships with low L/B ratios". Later on, research was done in order to be able to predict resistance for slender naval vessels with a "complex appendage arrangement and immersed transom sterns".

The total resistance as calculated by Holtrop & Mennen is:

$$R_t = R_f(1 + k) + R_{app} + R_w + R_b + R_{tr} + R_a \qquad (6.25)$$

R_f is the frictional resistance based on the ITTC-57 formula. The frictional resistance is multiplied with a form factor k. R_w is the wave-making resistance. R_b is the additional pressure resistance caused by the presence of a bulb. R_b is zero in this research since inland barges almost never have a bulb. R_{tr} is the additional pressure resistance of an immersed transom stern. R_a is, like in Van Terwisga's method, the additional model-ship correlation resistance.

The resistance caused by appendages is defined by:

$$R_{app} = 0.5 * \rho * V_s^2 * S_{app} * (1 + k_2) * Cf \qquad (6.26)$$

In fact, the appendage drag is calculated in the same way as the frictional resistance of the barge, now specified by the wetted surface of the appendage(S_{app}) multiplied by a form factor k_2. The approximate 1+k2 factors are shown in appendix 6.5.

This formula will be used in Van Terwisga's method as well since it is not specified there.

The exact specification of the Holtrop & Mennon method is not given in this report since it is 5 pages of formulas. The power prediction method has been programmed by prof. ir. Aalbers into an excel sheet. This sheet has been used to calculate the resistance of the barge.

6.2.1.4 Shallow water

As mentioned in the Bolt resistance prediction method, sailing in shallow water increases the resistance of the barge. The method developed by Karpov (Van Terwisga (a), 1989) is used to calculate the resistance of the barge when sailing in limited waters. This method is implemented in the Van Terwisga and the Holtrop & Mennen method. A shallow water resistance method is already incorporated into the Bolt method.

$$R_{shallow} = 0.5 * \rho * S * [(C_f + C_a)V_1^2 + C_r V_2^2] \qquad (6.27)$$

The resistance is split into two parts. The first part, $C_f + C_a$, exist of sum of friction based resistance coefficients, the second part, Cr, represents the pressure based resistance coefficients. Each part is multiplied with a different speed.

$$V_1 = \frac{V_s}{\alpha^*} \tag{6.28}$$

$$V_2 = \frac{V_s}{\alpha^{**}} \tag{6.29}$$

α* and α** are based on the figures as shown in appendix 6. These figures are functions of F_{nh} (Froude number based on river depth) and the ratio of the water depth and the draught of the barge (h/T). From these figures, it becomes clear that the influence of the ratio h/T is of great influence to the speed of the water along the hull of the barge.

6.2.2 Resistance components

Figure 6.4 gives a schematic overview of the main parameters. It is assumed that changes in the shape of the barge are of minor influence to the overall resistance of the barge. This is the "base"-shape of the barge from which the resistance calculations are done. The final shape of the barge will depend on for instance the propeller diameter and the amount of propellers.

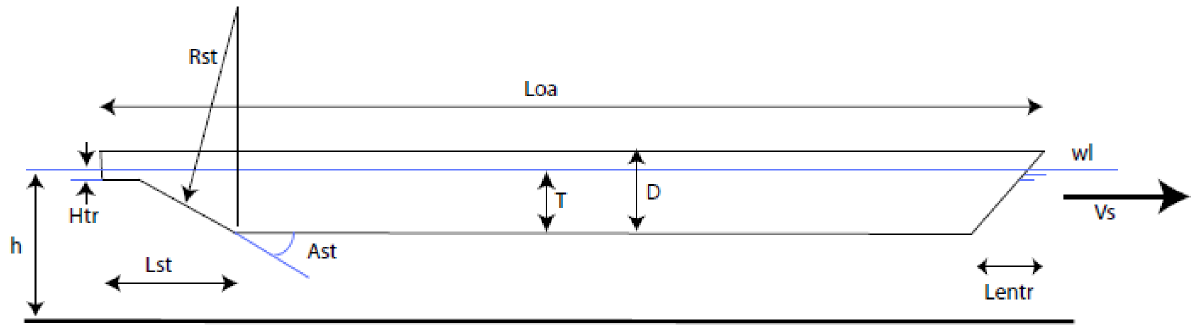


Figure 6.4 Overview main parameters barge

Appendix 6.6 shows the value of the input parameters for each of the three calculation methods.

An important aspect is the validation of the methods. Special attention has to be paid for the Van Terwisga method, since the L/B ratio should stay below 8. In fact, the L/B ratio is 12. The outcome of the Van Terwisga method will be compared with the two other methods in order to specify the validity of the method for this inland barge.

It is interesting to see how the components of the Van Terwisga method change with increasing speeds. Figure 6.5 shows this.

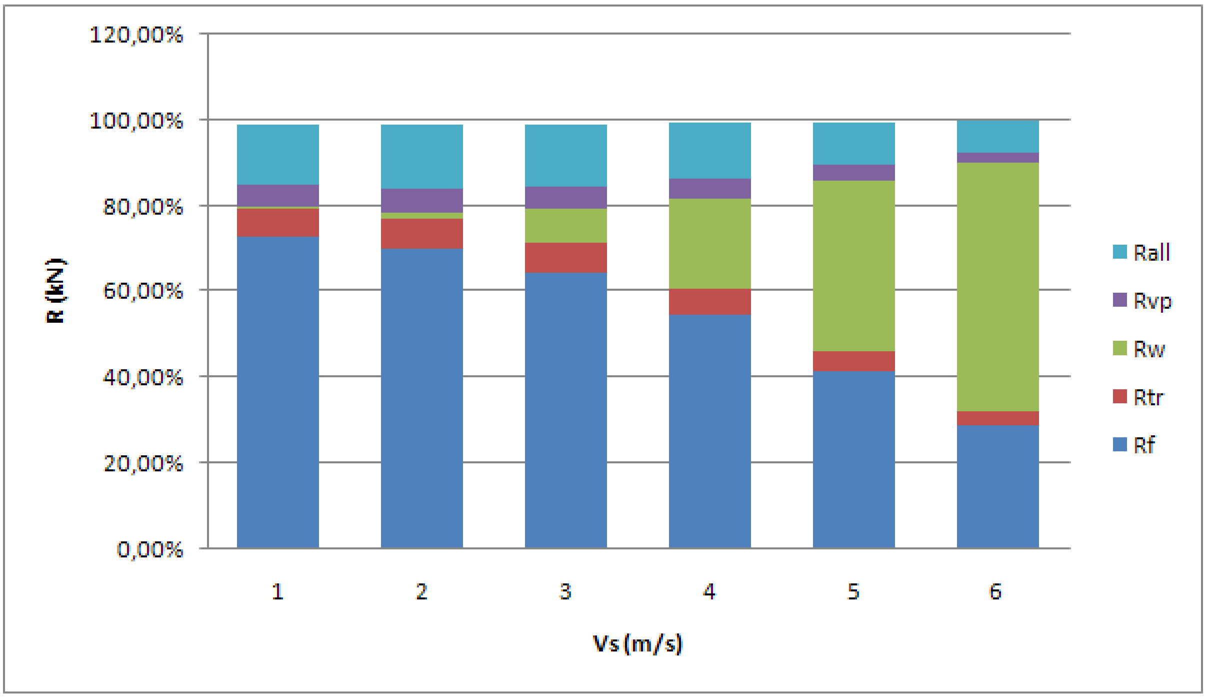


Fig. 6.5 Van Terwisga method resistance components deep water

This figure shows that R_w, the wave making resistance, becomes increasingly important with increasing speeds. This is according expectations. It has to be mentioned that this figure is based on deep water calculations. The corresponding shallow water resistance components are shown in figure 6.6.

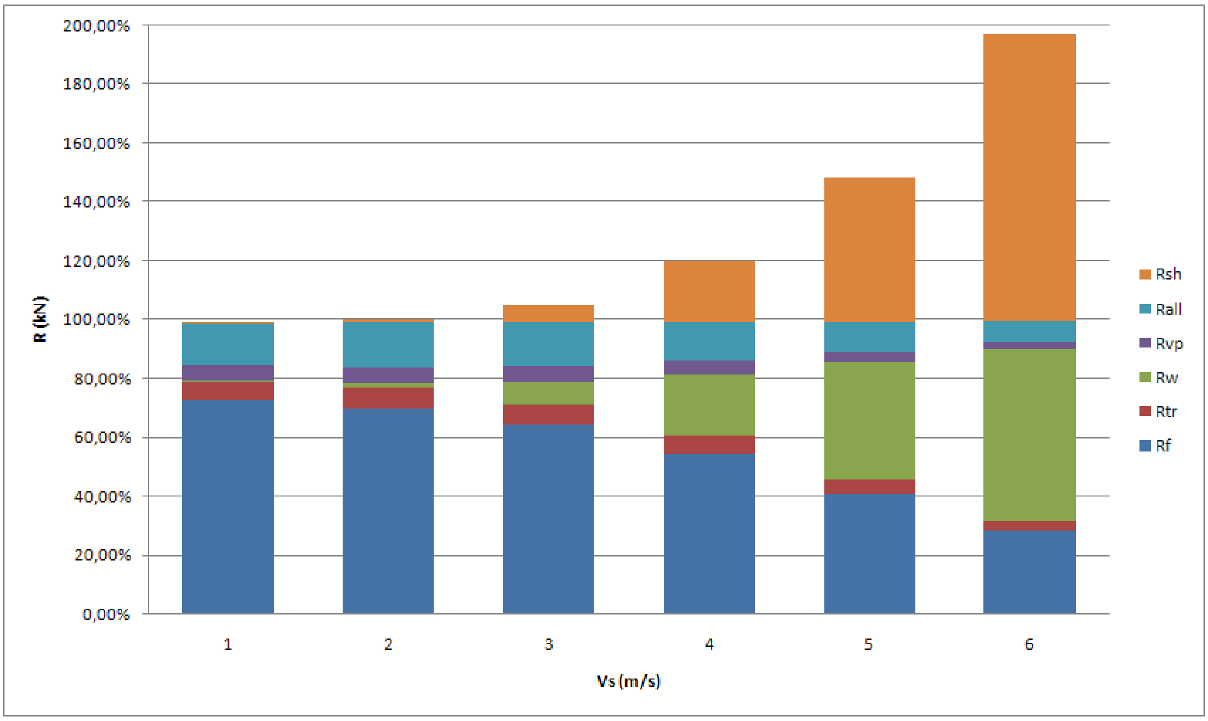


Fig. 6.6 Van Terwisga method resistance components shallow water

The shallow resistance is shown as a percentage of the deep water resistance. The influence of the limited water dimensions (h/T=2 in this case) becomes increasingly important at higher speeds. The combination of limited water depths and high velocities result in added shallow water resistance, which can become over 50% of the deep water resistance.

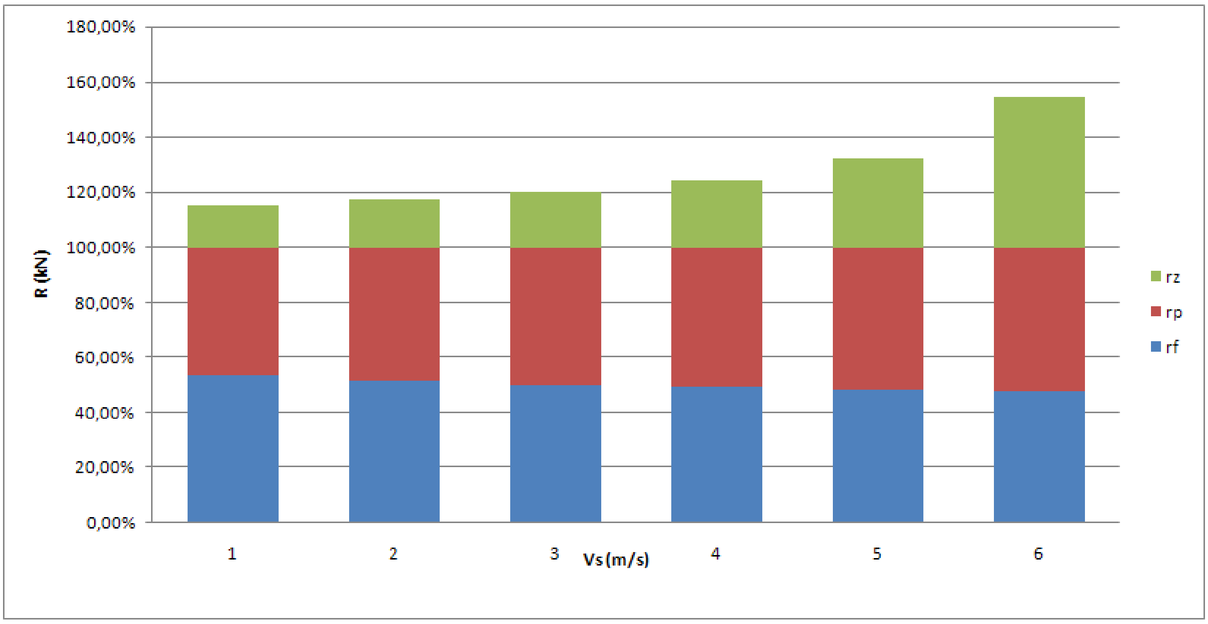


Figure 6.7 Bolt method resistance components shallow water

Figure 6.7 shows the resistance components of the Bolt method. There are some remarkable differences with respect to the Van Terwisga method. The most important is the structure of the deepwater part of the Bolt method. The ratio R_p/R_f is constant. The Bolt method (Bolt, 2003) is based on average main dimensions of barges. It is assumed that *for common inland navigation velocities, R_f and R_p should be of equal size*. This should be questioned since the wave making resistance component (R_p) should become bigger with respect to the frictional resistance if velocities increase. The physical behavior of R_p and R_f is such that the ratio of the two cannot be constant.

The shallow water resistance shows the same behavior as in the Van Terwisga method, it increases with increasing velocities. It has to be mentioned that the Bolt method shows added resistance due to shallow waters at lows speeds, opposite to the Van Terwisga method. The Bolt method should be questioned again. 15% Added resistance at 1 m/s is significant and maybe exaggerated a bit.

To complete the overview the outcome of the Holtrop & Mennen method is shown in figure 6.8. It becomes clear that the behavior of the H&M method is almost the same as Van Terwisga's method. The added and frictional resistance increase with increasing velocities.

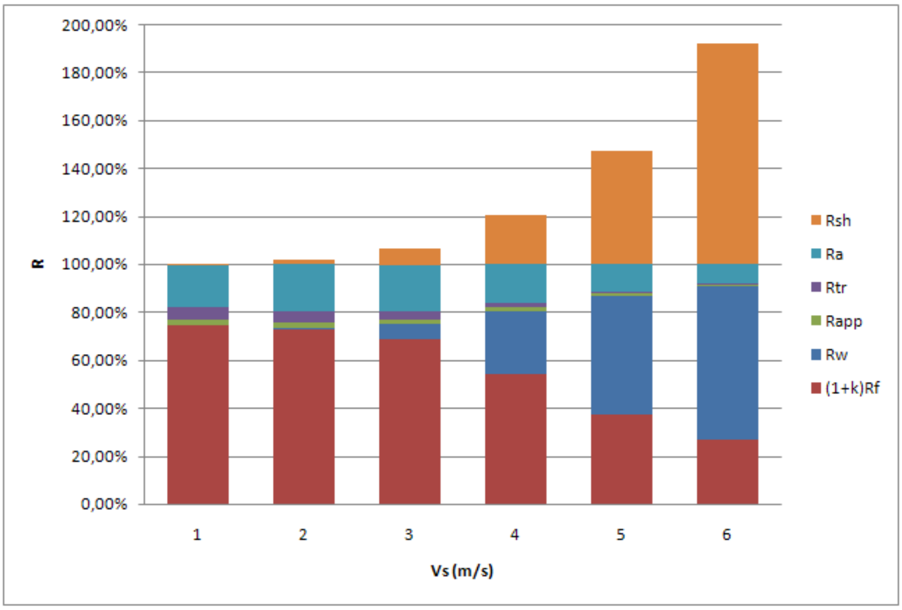


Figure 6.8 Resistance components H&M method shallow water

6.2.3 Resistance comparison

This paragraph will show the results of the resistance calculations and discuss the validation of the results.

6.2.3.1 Resistance calculation results

Figure 6.9 shows the result of the resistance calculation at different speeds in deep water. The total resistance (R_t) is plotted against speed (V_s). The Van Terwisga Method and the H&M method show the same trend with increasing speeds. It seems that the H&M method calculates a higher wave making resistance since the difference with the Van Terwisga method becomes significant at higher velocities.

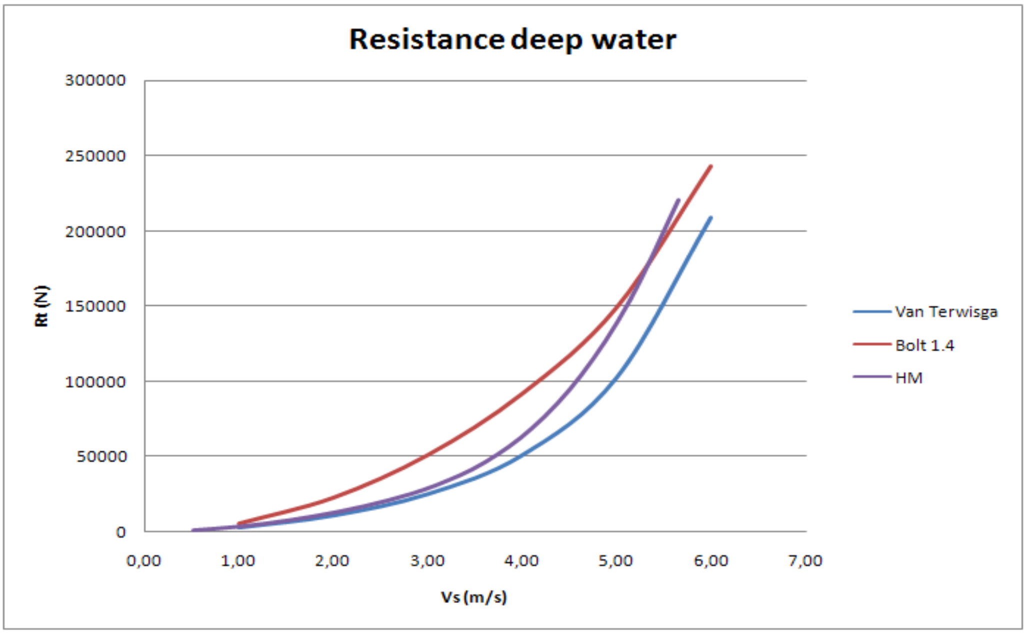


Figure 6.9 Resistance in deep water

It is of course interesting to compare these resistance curves with the shallow water ones. Figure 6.10 shows these resistance curves. The previous paragraph has shown a tremendous increase of resistance, due to shallow waters, at higher velocities. Figure 6.10 confirms this. From 4 meter per second, the resistance of the barge increases significantly. The Bolt method results in high resistance in the lower speed range if compared to for instance the Van Terwisga Method. This could be explained by referring to the fact that Ernst Bolt assumed his wave making resistance to be of equal size compared with the frictional resistance. This assumption results in an excessive resistance at lower speeds.

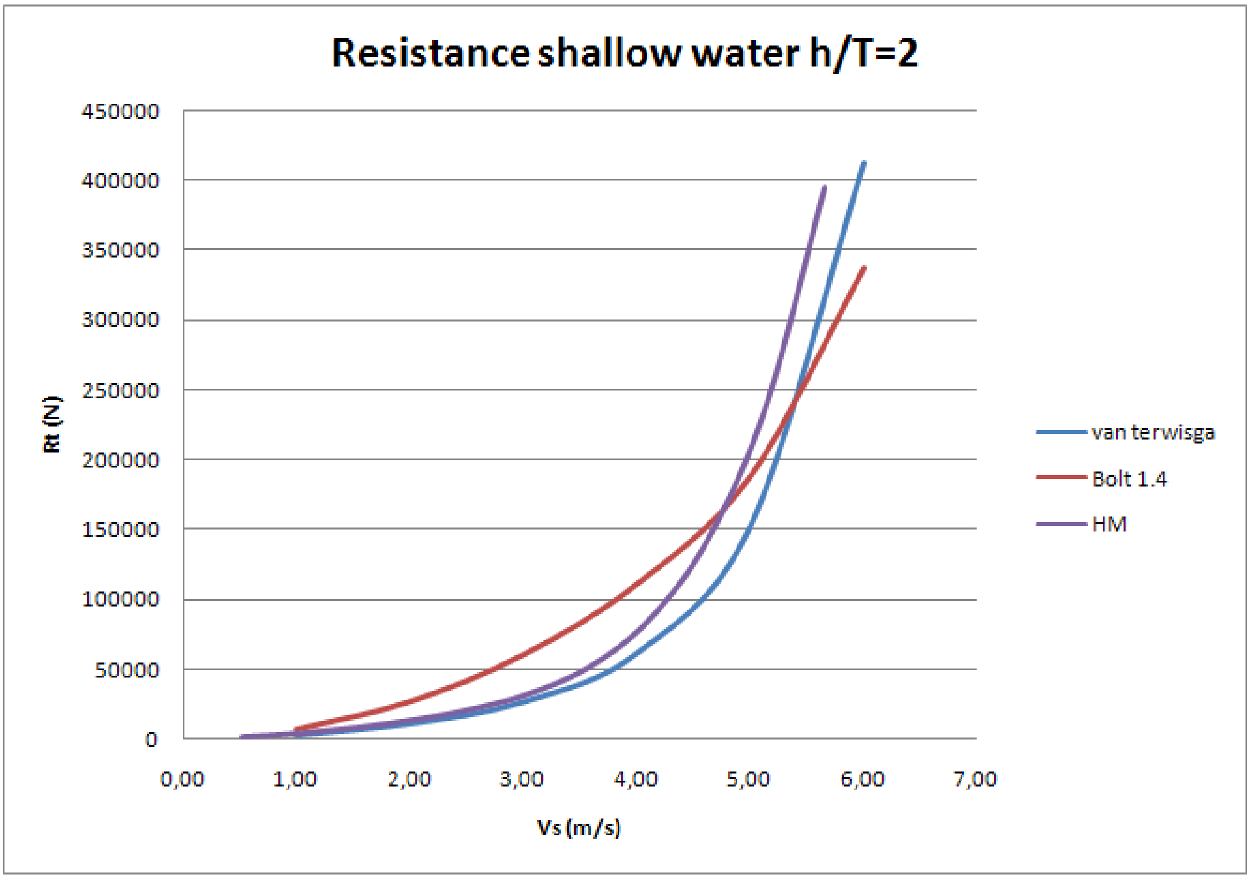


Figure 6.10 Resistance in shallow water

6.2.3.2 Validation Resistance results

As discussed before, the resistance calculation methods were developed for a different kind of vessels, or at least for different L/B ratio's (Van Terwisga method). It is therefore important to validate the results from paragraph 6.2.3.1.

Figure 6.11 shows the outcome of resistance calculations done with three differently sized barges. The L/B ratio of the developed barge is 12. To validate the calculated resistance, the resistance of two barges with an L/B ratio of 8 has been calculated. In case of the first one, the length and width are 135m/17m, and in case of the second one, the length is 92 meter and the width is 11.45. The calculated resistances have been divided by the volume of the displaced water, assuming a C_b ratio of 0.87. So in fact, the only variable is the L/B ratio.

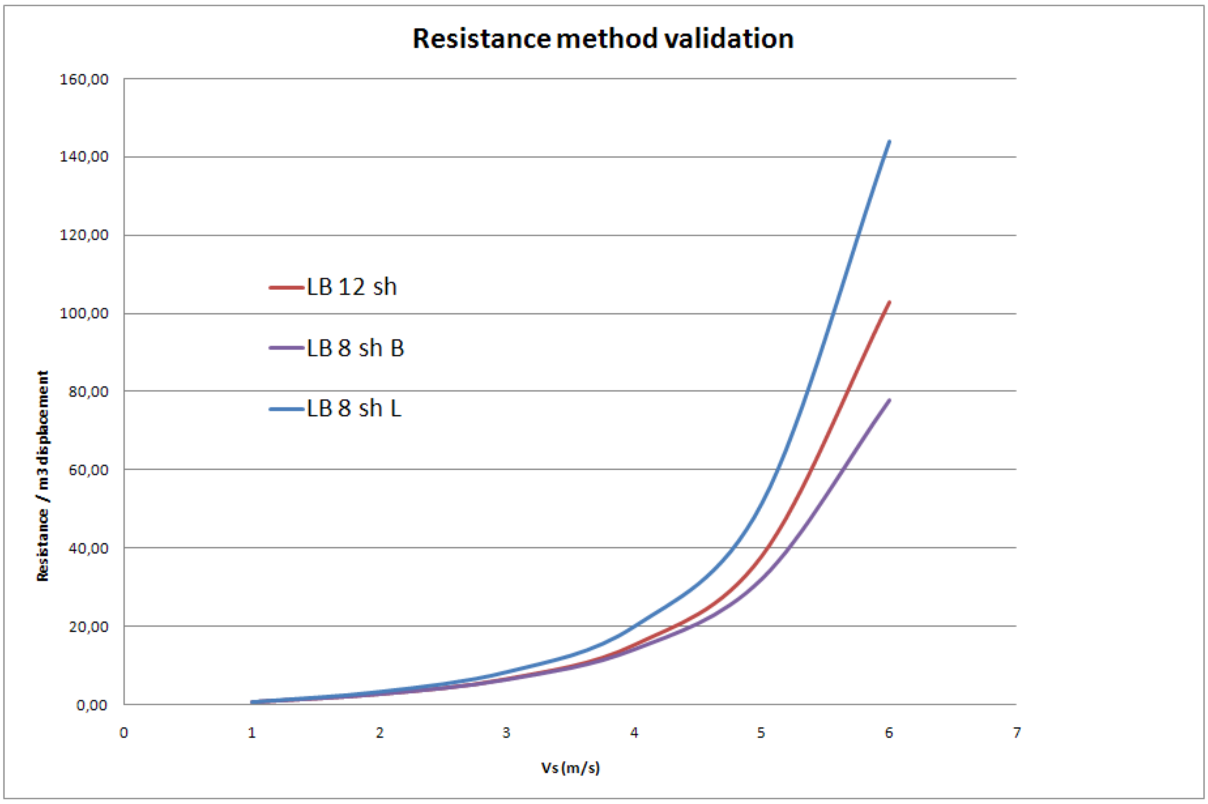


Figure 6.11 Validation calculation Van Terwisga method.

The legend of figure indicates whether the length ("LB 8 sh L") has been varied to 92m or the width ("LB 8 sh B") to 17 meter. "LB 12 sh" is the shallow water resistance per m^3 displacement of the barge with an L/B ratio of 12.

In fact, figure 6.11 gives no reason to state that the resistance calculation of the developed barge is invalid. The resistance per m^3 is between the two other calculated resistances.

A database of 50 inland barges has been created to be able to compare the outcome of the resistance calculation with the installed power onboard barges. Appendix 6.8 shows the data from the database. The resistance calculated paragraph 6.2.3.1 can be transferred into break power (P_b) using:

$$P_b = \frac{P_{eff}}{\eta_t} \qquad (6.30)$$

$$P_{eff} = R * V_s \qquad (6.31)$$

$$\eta_t = \eta_h * \eta_o * \eta_r * \eta_s * \eta_{gb} \qquad (6.32)$$

The total efficiency (η_t) is estimated to be around 0.45. This is a preliminary number and only chosen in order to be able to do a quick calculation with the calculated resistance curve.

Using these formula's (6.30-6.32), figure 6.10 is transferred into figure 6.12.

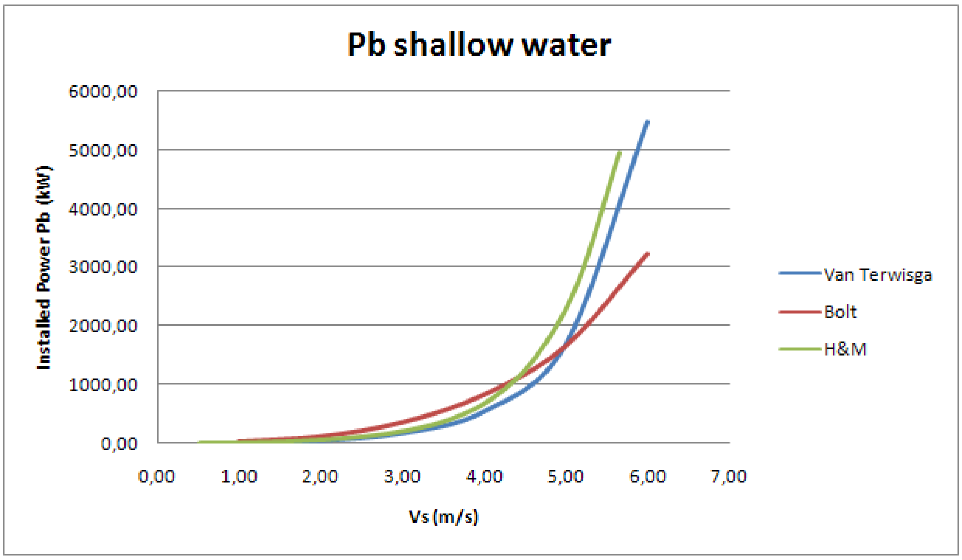


Figure 6.12 Installed power P_b based on resistance methods

The difference between the Holtrop & Mennen and the Van Terwisga method can be explained by the fact that the H&M method is ten years older than the Van Terwisga method and therefore based on less optimized ship designs. The half entrance angle of the waterline is of great influence on the wave making resistance of the barge. H&M returns a high wave making resistance. It can therefore be expected that the Van Terwisga method results in more accurate and realistic resistance numbers.

Figure 6.13 and 6.14 are based on the database of inland barges. They show the installed power onboard these barges versus the deadweight tonnage. Figure 6.13 shows vessels of 110 meter, whereas figure 6.14 only contains data from 135 meter barges. Two or three lines are added to each figure to show the predicted power of the barges, based on the Van Terwisga method. The draught of the barge is varied in order to create different deadweight tonnages. The length is fixed, as is the width of the barge. The predicted power is calculated for speeds of 4.5 and 5 meter per second since these are the velocities which can be expected on for instance the river Rhine.

A remarkable difference can be observed from these two figures. The installed power for 110 meter is between the 4.5 en 5 m/s line. The installed power onboard barges of 135 meter is much more then the power predicted by the Van Terwisga method.

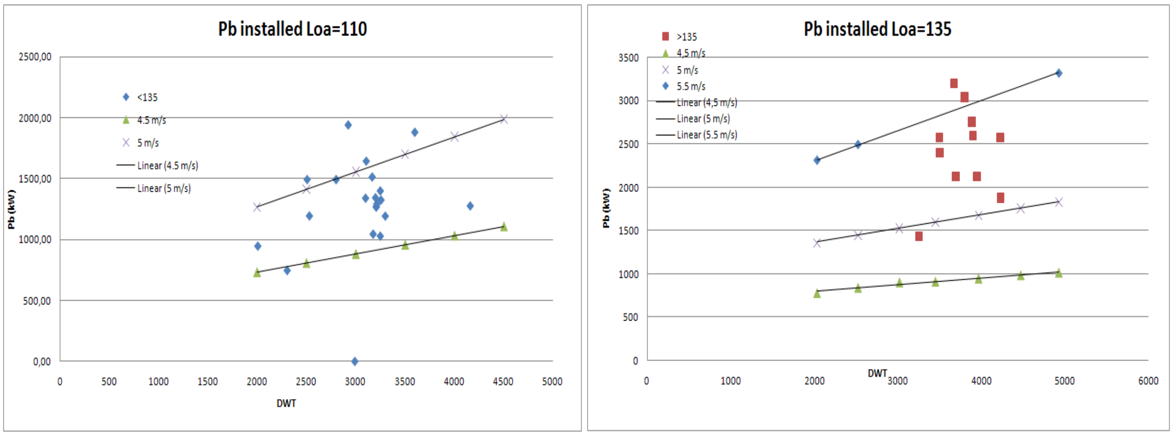


Figure 6.13 and 6.14, Installed power versus deadweight tonnage

The difference could for instance be explained by the assumption that installed powers are not always based on calculations, but on experiences from captains. One could design and optimize a barge for just one route but this would limit the operation range of the barge. As previously mentioned, variations in river dimensions and currents could explain the installation of an “unnecessary” amount of power. Some barges have supplementary power because they are allowed to sail in combination with a barge, placed in front of the powered barge. Rapids in the river can be a reason for added power as well. Non-quantifiable reasons for the excess of installed power are for instance that captains “just want a big engine” or want an engine “bigger than the neighbor’s”.

Incorporating the previously mentioned reasons for extra power into a design creates a “hybrid” barge. A barge which can sail in a variety of situations, but it is never sailing optimally from an economic and machinery point of view. The aim of this study is to design a barge for container transport on the Albert canal. It will be optimized for the Albert canal. From this point onwards, the main focus will be placed on this “Albert canal Barge”, but the “Hybrid Barge” will be designed as well, to show the differences in design and in the economic consequences of choosing either one of them.

6.3 Propeller calculations

The resistance figures as calculated in chapter 6.4 are the main input for the propeller calculations. The following questions will be answered in this chapter:

- Should one or two propellers be installed?
- What is the optimal diameter of the propeller(s)?
- What is the blade area ratio (A_e/A_o) of the propeller(s)?
- What is the optimal P/D (Pitch/Diameter) ratio?
- What is the open water efficiency (η_o) of the propeller(s)?

From an efficiency point of view, the diameter should be as large as possible. The P_d is limited by the draught of the barge, and by the shape of the aft ship. Determining the open water efficiency accurately is important when calculating the necessary amount of power which has to be installed onboard the barge in order to sail the design speed.

The blade area ratio is defined as:

$$\frac{Ae}{Ao} = \frac{(1.3 + 0.3Z)T}{(p_o - p_v)P_d^2} + k \tag{6.33}$$

In this case, T is the trust which the propeller will have to deliver. It is defined as:

$$T = \frac{R}{1 - t} \tag{6.34}$$

In this case, t is the thrust deduction factor: (Van Terwisga (a), 1989)

$$\begin{aligned} t &= 0.6 * w_t(1 + 0.67w_t) \quad (1\ propeller) \\ t &= 0.8 * w_t(1 + 0.25w_t) \quad (2\ propellers) \end{aligned} \tag{6.35}$$

$$w_t = 0.11 + \frac{0.16}{x} * Cb^x * \sqrt{\frac{\Delta^{\frac{1}{3}}}{Pd}} + \Delta w_t \tag{6.36}$$

Table 6.1 shows the resistance at two different velocities. These numbers are equal to the outcome of the resistance calculations from chapter 6.4.

Bargetype	Vs (m/s)	R (kN)
Albert Canal	3.3	34
Hybrid	5	152

Table 6.1 Resistance input propeller calculations.

The propeller diameter is chosen as 2.4 meter. The design draught is 2.9 meter. To limit the propeller hull interaction, which could lead to noise and vibration, a clearance of about 15% of the P_d should be taken. A 5% clearance from the bottom of the barge leads to the defined diameter of 2.4 meter. If the aft ship is designed according to appendix 6.8, the water level goes up as a result of suction. This would allow a larger propeller diameter. It can however be questioned what will happen with the open water efficiency if the barge is not loaded to its design draught. The propeller will become surface-piercing and since it is not designed for this condition, it is likely that the efficiency will drop.

The open water efficiency can be increased by installing a duct. The duct generates propulsive lift and increases the flow around the existing propeller. So in fact, a duct and a small propeller can have the same efficiency as a normally sized propeller without a duct. The shape of a propeller blade in a duct can be optimized in such a way that efficiency losses near the tip (e.g. tip-vortex) are significantly reduced.

To calculate the optimum propeller configuration, an excel sheet has been used which was created by Ir. J.Frouws. Based on Holtrop & Mennen calculations and propeller data from the Maritime Research Institute Netherland (MARIN), it is possible to optimize the specifics (P/D, n_{rpm} and η_o).

V (m/s)	Ds (-)	P/D (-)	n_{rpm}(1/min)	D_p (m)	Z (-)	A_e/A_o (-)	η_{opt} (-)	$\eta_{offdesign}$(-)
3.3	1	0.67	151	2.6	3	0.374	0.40	0.31
3.3	2	0.79	144	2.6	2	0.193	0.60	0.47
5	1	0.70	273	2.6	4	0.977	0.27	0.35
5	2	0.81	252	2.6	4	0.691	0.39	0.48

table 6.2 results propeller calculations

Table 6.2 shows the results of the propeller calculations. It becomes clear that installing 2 propellers results in an efficiency increase of 50% with respect to the 1 propeller option. The most efficient situation is sailing at 3.3 m/s with two propellers. The propeller load is low resulting in few propeller blades and a low blade area ratio. These parameters have a great influence on the propeller efficiency. Sailing with the “hybrid” barge at a lower speed leads to an efficiency decrease with respect to the dedicated “Albert canal” design of 12%.

The A_e/A_o ratio of the two 5 m/s calculations indicates that the propellers are powered with a significant trust/blade area ratio. The amount of propeller area is not sufficient to increase the efficiency. Installing ducts can increase the efficiency. Table 6.3 shows the results of ducted propeller calculations.

V (m/s)	Ds (-)	P/D (-)	n_{rpm}(1/min)	D_p (m)	Z (-)	A_e/A_o (-)	η_{opt} (-)	$\eta_{offdesign}$(-)
5	2	1.13	197	2.6	3	0.688	0.50	0.48

Table 6.3 propeller calculations with ducted Ka4-70 propeller (nozzle 19a)

The amount of revolutions has reduced whereas the P/D ration has gone up. The efficiency of the propeller has increased with 11 percent. It becomes clear from that two propellers should be preferred over one propeller and that in case of the hybrid, 5 m/s second, barge the ducted propellers will deliver a higher efficiency than non-ducted propellers.

6.4 Propulsion concepts

There are many different possibilities to trust a barge. Before the propulsion systems can be designed, the demanded powers have to be known. The effective power (P_{eff}) is the power which the propeller will have to deliver to thrust the barge to its design speed. The break power (P_b) represents the power which the main engine(s) will have to deliver to the propeller shaft.

$$P_{\mathrm{eff}} = R * V_{\mathrm{s}} \tag{6.37}$$

$$P_{\mathrm{b}} = \frac{P_{\mathrm{eff}}}{SM * \eta_{\mathrm{t}}} \tag{6.38}$$

The Sea Margin (SM) is assumed to be 15%. The total efficiency η_t (formula 6.32) is expected to be 1.14*η_o for 1 propeller and 1.05*η_o for 2 propellers. The shaft efficiency is assumed to be 0.99. The gearbox efficiency is assumed to be 0.98. The hull efficiency is :

$$\eta_{\mathrm{h}} = \frac{1-t}{1-w} \tag{6.39}$$

Since the two input parameters of formula 6.39 depend on the amount of propellers (see formula 6.35 and 6.36), the hull efficiency is different for a barge with one or two propellers. The calculated powers are shown in table 6.4.

V (m/s)	Rnom (kN)	Peffnom (kW)	Rmax	Peffmax	ηt	ηtmax	Pbnom (kW)	Pbmax (kW)
3,3	35	115,5	39	128,7	0,63	0,60	183	215
5	152	760	177	885	0,49	0,47	1551	1883

table 6.4 calculated powers

Table 6.4 shows the calculated power for the (nominal) design condition (noted by "nom") and the demanded powers in case of sailing at the maximum draught. The barge should be able to sail on its design speed, even if it's loaded beyond its design draught.

The demand for electrical power is mainly caused by the presence of the two conventional cranes. These demand 226 kW each. The bow thruster will need electrical power as well. The amount of power for the bow thruster is based on the database which has been used before to compare the power calculation with the powers installed onboard existing barges. Figure 6.15 gives an overview of the installed bow thruster power with respect to deadweight tonnage.

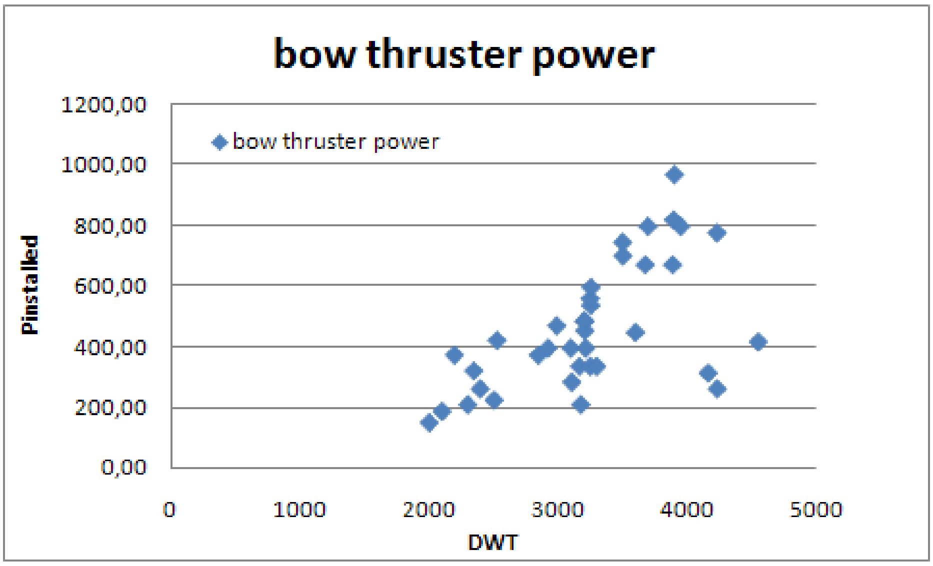


Figure 6.15 bow thruster power based on database

This figure shows a great variance in the installed powers. Equally sized barges can have installed bow thruster powers which differ up to a factor 3 or 4. In fact, the installed amount is totally arbitrary. It is probably based on the experience of the captain. If the current in the river is strong and a barge leaves a port upstream, a significant amount of bow thruster power is useful. A bow thruster power of 300 kW has been chosen. It is assumed that 300 kW is sufficient to moor and unmoor autonomously.

6.4.1 Propulsion system Albert canal barge

This paragraph will describe and evaluate two propulsion concepts.

Concept 1) Diesel Electric

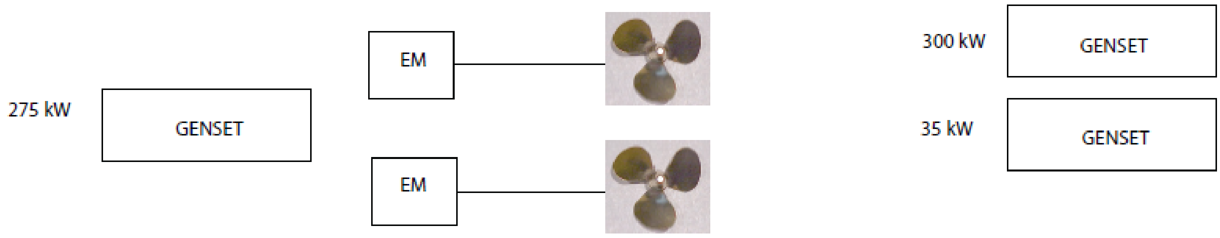


Figure 6.16 Diesel electric concept Albert Canal Barge

This concept has great flexibility with respect to the location of the Generator Sets (gensets). The 275 kilowatt genset is for propulsion whereas the two other gensets together will have to supply the two cranes with electric power. The two “EM” boxes are Electro motors which generate mechanical forces for the propellers. These propellers can be fixed ones with a horizontal axis, but the installation of so-called rudder-propellers (or Z-drives) is also possible.

The 300 kW genset delivers power to the bow thruster, while the 35 kW generator should supply the vessel with electric power in case of emergency and when the barge is not sailing nor loading or unloading. The combined power of the 275 and 300 kW Genset is more than sufficient to fulfill the energy demand from the offloading equipment.

Concept 2) Diesel Direct

This most remarkable feature of this concept is the fact that the Diesel Engine (DE) generates mechanical power to the gearbox which transfers it to the propellers, or to the generator. The gearbox will therefore be a complex and probably expensive one. The propellers shown in figure 6.17 can be Z-drives as well. The 300 kW and 35 kW gensets have the same function as in concept 1.

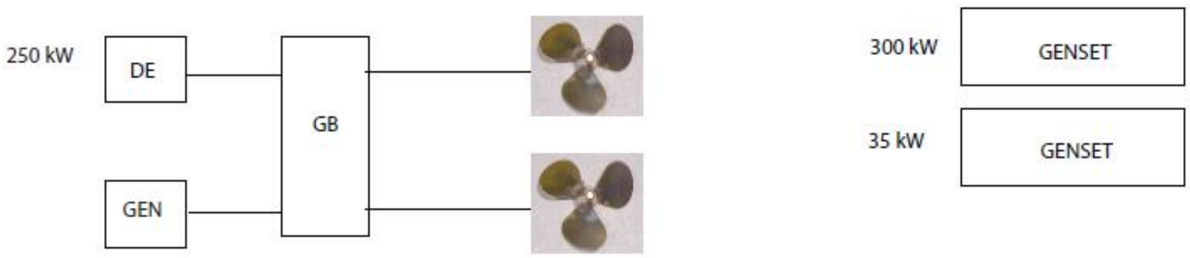


figure 6.17 Diesel Direct concept Albert Canal Barge

It is possible to install the generator on the other end of the engine (not the gearbox end). This would demand significant engine room length which is not available. In fact the length of the engine room is already smaller if compared to similar sized barges. This is a result of the presence of two conventional cranes without a reduction in transport capacity. Creating space for these two cranes limits the available space. It is not possible to decrease the length of the forepeak since this is prescribed by classification societies.

One of the major differences between these two concepts is the presence of a gearbox in the second concept. The position of the diesel engine (and generator) is fixed whereas the corresponding genset in concept one can be placed anywhere. This gearbox is not a standard one and therefore expected to be very expensive. The ratio of the in and outgoing rpm's (i) is about 9 where ratio's between 2 and 5 are normal ones. The calculation sheet used for the comparison of the propulsion concepts indicates that such a gearbox will cost 200.000 euro. A "normal" gearbox with a input power of 300 kilowatt would cost around 30.000 euro.

The 300 kW and 35 kW Gensets will be placed just aft of the collision bulkhead. The 275 kilowatt genset will be placed in the aftship. Since the 35 kilowatt genset is the emergency source of power, it should be placed as far as possible from the engine room. The 300 kW genset is placed just aft of the forward collision bulkhead as well since it is the power source for the bow thruster.

Appendix 6.9 gives the technical specification of the Diesel engine (Cat 3406C) which is chosen for the Diesel Direct concept. Appendix 6.10 shows the technical data of the genset (Cat 3406 c Genset) which is used in either of the concepts. The specifications of the emergency generator are shown in appendix 6.11.

Table 6.5 shows the outcome of the comparison from these two concepts. It has to be mentioned that this is a preliminary and exploratory cost calculation. Some posts maybe empty where in fact they should not be. The aim of the calculation is to show the differences between the concepts. The exact outcome of the calculation can therefore be doubted, the trend not. The concepts are much alike, except one post.

As previously mentioned, the gearbox from the Diesel Direct concepts is very expensive. In fact, the gearbox would in this case be the decisive factor. The electro motors are not expected to be expensive. The Diesel electric concept should therefore be favored over the Diesel Direct concept.

	Diesel Electric			Diesel Direct	
Summary	Mass	Costs		Mass	Costs
	ton	€ -		ton	€ -
Engine room					
All diesels	5,4	€ 137.429		4,0	€ 140.853
Cooling water system	2,1	€ 41.131		1,6	€ 32.976
Gearboxes	1,74	€ -		5,04	€ 209.666
Generators & Emotors	7,99	€ 52.803		6,55	€ 43.060
Electrical motors heavy	2	€ 17.559		0	€ 220
Subtotal	19,13	€ 248.921		17,28	€ 426.775
Electrical and other spaces					
Converters	0,71	€ 47.905		1,10	€ 53.350
Switch boards					
Motors total	1	€ -		2	€ -
Subtotal	1,27	€ 47.905		3,39	€ 53.350
Space in accommodations					
exhaust gas system	0,4	€ 3.796		0,3	€ 3.481
ventilation system	3,08	€ 30.778		2,86	€ 28.635
Subtotal	3,46	€ 34.574		3,21	€ 32.116
Structural steel	74	€ 294.831		72	€ 286.101
Grand total	98	€ 626.232		95	€ 798.341

Table 6.5 Results comparison propulsion concepts Albert Canal Barge

There is however a possibility to reduce the cost of the gearbox. Reducing the rotational rate from the engine to the preferred propeller rpm is also possible by means of a mechanical belt. This is a very simple, but efficient system to reduce the RPM from the engine. Figure 6.18 shows a simple example of a mechanical belt.

figure 6.18 Mulco mechanical belt (Mulco inc., 2009)

It is expected that installing a belt will reduce the cost advantage of the Diesel electric concept to zero. Neither of the two concepts is propelled by Z-drives, or so-called rudder thrusters. The main disadvantage of these propulsion systems is the fact that the two perpendicular couplings reduce the delivered power to the propellers with about 10%. An advantage is the fact that rudders are no longer necessary, reducing the resistance of the barge. The price and maintenance cost of these rudder propellers is expected to be higher than conventional propellers.

Another important evaluation parameter is the location of the Electro motors, Diesel Engines and Generator sets. As previously mentioned, the diesel electric concept is very flexible with respect to the arrangement of engines.

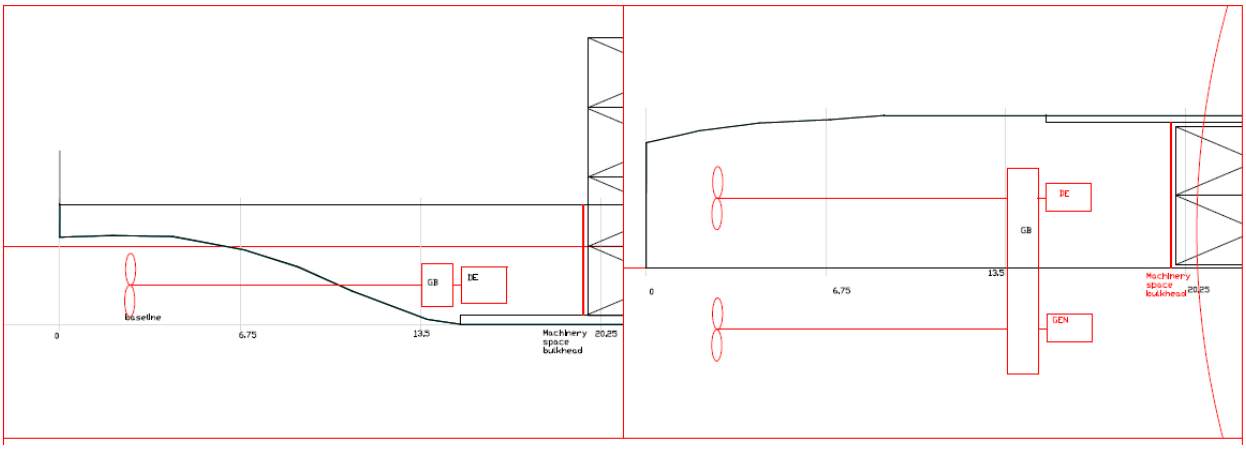


Figure 6.19 Engine room arrangement diesel direct concept (side- and topview)

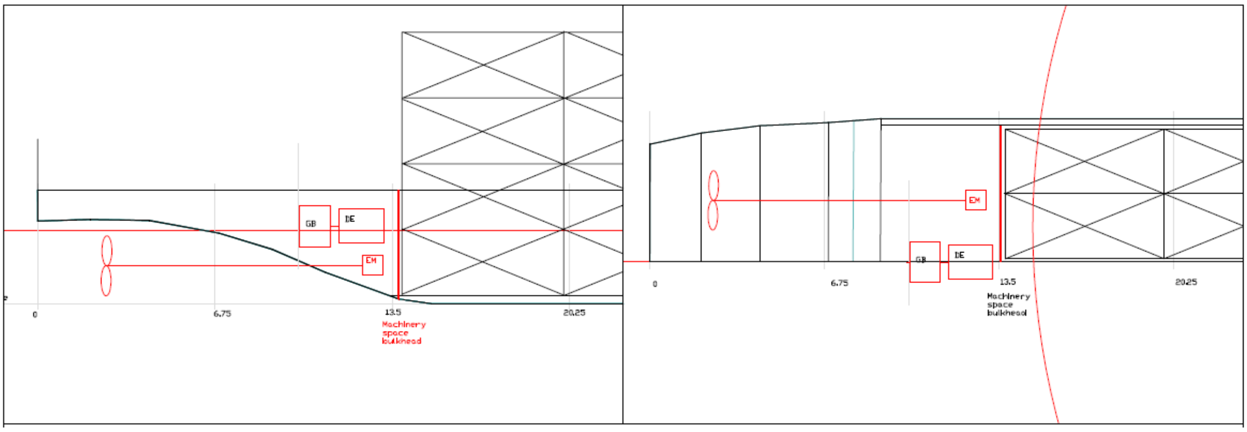


Figure 6.20 Engine room arrangement diesel electric concept (side- and topview)

Figure 6.19 and 6.20 show the engine room arrangements from both concepts. The most remarkable difference is the position of the machinery space bulkhead. In case of the diesel direct concept, the bulkhead is positioned just aft of the last container. The electric motor is so small that the bulkhead can be placed more aft than in case of the diesel direct concept. The generator set is positioned higher and more aft in case of the diesel electric arrangement. In fact, the bulkhead is moved aftwards so that 16 TEU more can be placed in the hold.

The diesel electric arrangement results in a capacity increase of 16 containers, or equivalently 7%. It might be possible to store containers on top of the engine room. The construction of the engine room will have to be adapted and strengthened to cope with the increased load. It should be possible to transport 8 containers on top of the engine room. This compensates the deficit of the diesel direct concept with respect to the diesel electric concept.

Appendix 6.12 and 6.13 show the total arrangement of the two barges with the two different propulsion concepts incorporated. The extra containers are positioned between the cranes. So the arrangement of the containers in longitudinal direction has changed from 5-6-5 to 5-7-5 TEU’s.

6.4.2 Propulsion system Hybrid barge

The hybrid barge is developed to compare the economic performance of a dedicated Albert canal barge with a more common “hybrid” barge. The following concept has been chosen as the propulsion concept for the hybrid barge:

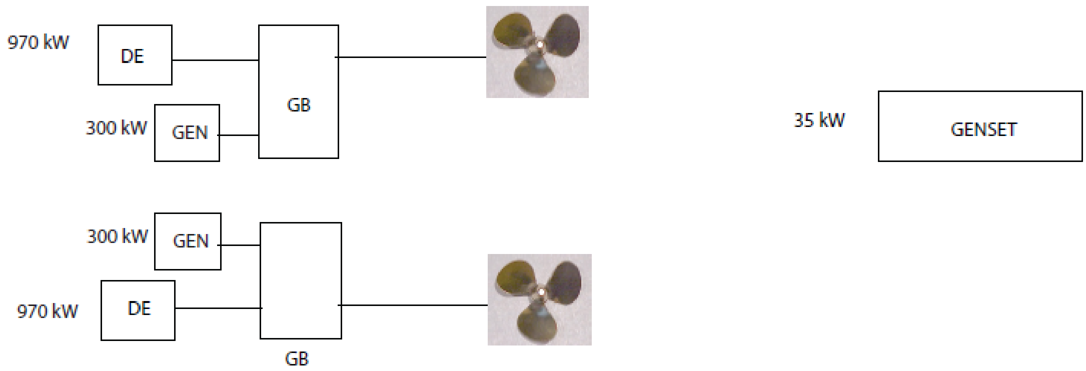


Figure 6.21 Propulsion concept hybrid barge

This concept has been chosen since it is a common concept for larger inland barges. The generator’s can also be installed on the flywheel end of the diesel engines instead of on the gearboxes. Installing the generators at the flywheel end of the engines would demand significant engine room length of which it is questionable whether that is available.

The specifications of the main engine can be found in appendix 6.14. These caterpillar C14 engines are capable of delivering 970 kilowatt at 1800 rpm, but are also capable of delivering 135 kW. The engine rpm will drop to 950 rpm. The fuel usage will go up from 205 g/kWh at 1800 rpm to 215 g/kwh at 950 rpm. This might become important when comparing the operational behavior of the developed concepts.

As in paragraph 6.6.1, an excel sheet from ir. J. Frouws has been used to compare the hybrid concept with the two albert canal concepts on cost and weight (a.o.). Table 6.6 shows the outcome of the calculated costs.

Summary	Mass	Costs
	ton	€ -
Engine room		
All diesels	5,5	€ 228.033
Cooling water system	1,7	€ 34.066
Gearboxes	15,37	€ 607.058
Generators	1,00	€ 56.050
Electrical motors heavy	2	€ 220
Subtotal	25,38	€ 925.428
Electrical and other spaces		
Converters	1,15	€ 56.887
Switch boards		
Motors total	1	€ 4.327
Subtotal	1,71	€ 61.214
Space in accommodations		
exhaust gas system	1,1	€ 10.666
ventilation system	4,56	€ 45.599
Subtotal	5,63	€ 56.264
Structural steel	81	€ 322.233
Grand total	113	€ 1.365.139

Table 6.6 results propulsion concept calculation hybrid barge.

From table 6.5 and 6.6, it becomes clear that the investment in equipment for the hybrid barge is almost twice the investment needed for the Albert canal barge. Again, the gearboxes are very expensive. This concept is 20 ton heavier as well.

6.5 Stability

The stability of a barge is measured by the initial GM value. Class rules for container inland barges require a minimum GM value of 0,5 meter if the movement of the containers is limited by guiding cells or lashings. Otherwise, the minimum GM value is 1,0 meter.

6.5.1 Main parameters

Figure 6.22 is a transverse view of the barge with the main parameters for stability calculations.

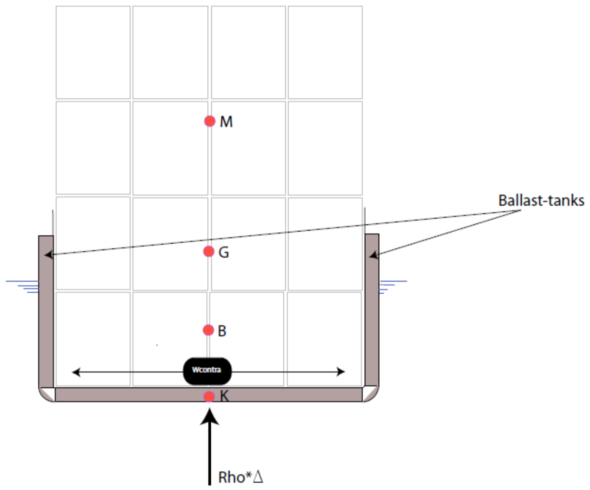


Figure 6.22 Main parameters stability calculations sailing condition

The grey part represents the double hull and double bottom of the barge. If necessary, these can be used for ballast water to trim the barge. The W_{contra} represents the weight which can move in a transverse direction to create a righting moment (if necessary) when loading and unloading containers. The K is the keel, or bottom of the barge from which the other parameters are measured or calculated. The B represents the centre of buoyancy. Since the main frame is nearly square, B is equal to the draught divided by two. The mass centre of gravity of the Barge is represented by G. The initial Meta centre height, M, is the point where which the buoyant Archimedes force crosses the center line. This point shifts a bit, depending on the inclination angle. The black arrow indicates the position of the Archimedes force which is a result of the displacement of the barge.

Figure 6.23 shows a schematic overview of the most important parameters when loading and unloading containers.

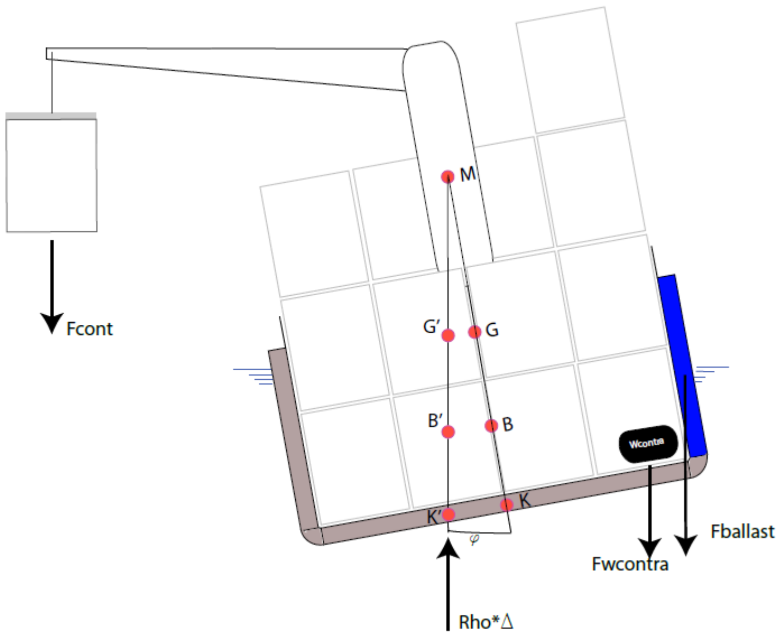


Figure 6.23 Main parameters stability calculation offloading condition

The heeling moment is caused by the crane itself, since its centre of gravity is no longer on the longitudinal axis of the barge and by the weight of the container. The angle of inclination is represented by ϕ. The centre of buoyancy B shifts to B' since the shape the displaced volume changes when inclining. The Archimedes force goes through B', resulting in a righting moment around G. $F_{wcontra}$ and $F_{ballast}$ are caused by the presence of the contra weight and the added ballast water. These forces result in righting moments as well.

An equilibrium state is achieved when the sum of the righting moments is equal to the canting moments. The maximum heeling angle is assumed to be 5 degrees (Bureau Veritas (A), 2009).

The program Delftship has been used to do stability calculations. An overview of the calculated lightweight factors including the locations of their centre of gravity has been given in Appendix 6.15. The two cranes are considered part of the lightweight as well. These cranes have been simulated to exist of two parts. The first one is the fixed, non rotating part. The rotating boom of the crane is simulated separately since its mass centre shift from the centerline sideways, resulting in a heeling moment. The weight of the boom is 31 ton and can therefore create a non-negligible heeling moment when offloading containers.

Appendix 6.15 contains a "Miscellaneous" table as well. This table describes the location of mass centers for the four container layers as well as the size and mass centre of the contra weight.

6.5.2 Stability simulations

Two unloading situations have been simulated at a variety of occupation rate. The first situation, "two containers high" represents the unloading of two containers, weighing each 30 ton, nearby the barge. When loading or unloading, this centre of gravity from the container shifts to the outer point of the boom. Unloading containers near the barge results in the fact that the crane's boom has to go up, shifting the centre of gravity from the container upwards, increasing the KG-value and thus reducing the GM value. The heeling moment less of a problem, the reduction in GM value could be.

The second situation, "two containers" far, simulates the unloading of two containers as well. The canting moment has been maximized in this case. In this simulation, the containers are unloaded at 25 meter from the barge, creating a significant heeling moment.

These two unloading situations have been simulated for four occupation rates. In fact, the amount of containers onboard the barge has been reduced by limiting the amount of containers on top of each other. Said in another way, the stability of the barge has been calculated with 0,1,3 and 4 container layers. The exact outcome of the stability calculations can be found in appendix 6.16.

Cont.Layers	(un)loading high/far	GM (m)	T (m)	Contra Weight (ton)	Water Ballast (% of 203 ton)	Heel (degr.to SB)
0	High	10.6	0.88	100	0	2.79
0	Far	10.8	0.92	100	30	5.19
1	High	5.72	1.56	100	0	2.79
1	Far	6.00	1.61	100	30	5.06
3	High	1.68	2.89	100	0	4.88
3	Far	1.91	2.98	100	70	4.99
4	High	0.65	3.42	100	30	4.65
4	Far	0.83	3.52	100	100	5.11
0	-	12.2	0.84	100	0	0
4	-	0.88	3.35	100	0	0

Table 6.23 Results stability calculations Delftship

Table 6.23 shows the results of the stability calculations. Delftship has calculated that the maximum volume (and equivalently the maximum weight) of water ballast is 203 m^3. It becomes clear that the minimum GM value is not always achieved. In fact, when loading or unloading at a 100% occupation rate, the GM value drops to 0.65. This is still a stable situation. The GM value can be increased by adding ballast water in the double bottom. This would decrease the KG value and therefore increase the GM value. The capacity of the double bottom is just sufficient to lower the KG value to achieve a GM value of 1.0 when sailing the barge.

It has to be mentioned that the GM value is only insufficient if the barge is fully, or at least more than 94% loaded. If this is the case, and the captain decides to unload two maximum loaded containers at the same time, only then decreases the GM value below 1.0. It can thus be questioned whether the insufficient GM value will occur at all and cause any stability issues.

From table 6.23 it becomes clear that the capacity for water ballast is only fully used in one occasion. The question arises whether it is possible to reduce the contra weight and to increase the water ballast. This is not possible. If for instance the barge has just unloaded a container on the quay, it does no longer encounter the heeling moment from the container anymore. This results in an excessive righting moment and subsequently heel to port! The inclination to port would exceed the maximum of 5 degrees. The contra weight has to be moved to starboard to prevent excessive heeling. It is not possible to actively control the amount of water ballast at such a rate that excessive heeling can be prevented.

The contra weight will be located underneath the crane. The crane is located between two bulkheads. The distance between these bulkheads is 4 meter. Onboard the AMSbarge, the Mercurius craneschip, such a system is already in place and functioning. The amount of movable ballast onboard the AMSbarge is two times 30 ton. It is therefore assumed that a system with movable ballast is technologically feasible. This thesis will not further address the technical specifications of this system.

The calculations have been done for the 5-6-5 TEU container configuration. In chapter 6.6, it was concluded that more containers could be stored onboard the barge, depending on the propulsion concept. With respect to the 5-7-5 TEU configuration, it can be expected that changes in the outcome of the stability calculations are minor since the center of gravity of the added containers in the transverse direction is the same as the containers which were already in place. Adding containers will only influence the trim of the barge. This can be corrected with ballast water.

In case of the diesel direct concept and the possibility of storing containers on top of the engine room, the KG value might increase a bit. As a result of this, the GM-value will decrease. Since the added weight is a small percentage of the total displacement and the center of gravity of the containers is not far from the existing KG-value, the change in GM is expected to be minor and insignificant.

6.6 Position wheelhouse

The position of the wheelhouse should be considered as a variable as well. It is often assumed that the wheelhouse should just be place in the aft part of the barge, above the engine room. In fact, the installed machinery is responsible for noise and vibrations in the wheelhouse because of its location above the engine room. One could consider locating the wheelhouse in the forward part of the barge. This has been implemented before on the Neokemp, a small inland container barge. The cost of the wheelhouse could be reduced since it is no longer necessary to have a wheelhouse with variable airdraft.

Designing the wheelhouse near the forward bulkhead creates a situation where containers can be placed on top of the engine room. The transport capacity of the barge can thus be increased there. The problem arises that if one would transport for instance 16 containers on top of the engine room, the barge will trim backwards. The barge displaces a very limited amount of water underneath the engine room, or said otherwise; the buoyant forces there are small. The trim can be compensated with water, but transporting water will not add to the economic success of the barge.

Sailing 24 hours per day is only allowed with at least 5 people onboard. The dimensions of the wheelhouse will therefore be significant. It is not allowed to use the available space in front of the collision bulkhead as a part of the wheelhouse. It is expected that the presence of the wheelhouse will limit the transport capacity in the forward part of the barge. The wheelhouse will occupy a certain amount of space which could otherwise serve as a transport hold.

The position of the wheelhouse influences the sailing behavior of the barge as well. Captains will have to be trained to sail with a barge which is not in front of them but behind them. Sailing towards a lock becomes more difficult. It can be questioned whether the conservative inland navigation sector will accept and implement such a nonconventional location of the wheelhouse.

It is therefore chosen to locate the wheelhouse in the aft part of the barge, on top of the engine room.

6.7 Conclusion

Two barges have been developed with significant differences. Although the hull shapes are the same, the propulsion system is not. The amount of installed power has to be increased to 1800 kW in case of the Hybrid barge. The propellers differ significantly as well. The transport capacity of the Albert canal barge is 258 teu. The Hybrid barge will be able to transport 242 twenty foot containers.

Chapter 5 has shown the significance of increasing the transport capacity with respect to the costs of transport. More is better in this case. The outcome of the propulsion system comparison for the Albert canal barge is therefore a logical one. The diesel electric concept results in a capacity increase with respect to the diesel direct concept of 16 TEU and should therefore be preferred over the diesel direct concept. In fact, the diesel electric propulsion system is more expensive than the diesel direct system and requires higher fuel consumption per kWh. It could therefore be expected that the diesel direct system has to be preferred over the diesel electric system. The difference in transport capacity makes up for the increase in investment and operational costs, in case of the Albert canal barge.

In case of the Hybrid barge, diesel electric should not be favored over diesel direct. The increased investment costs and increased operational costs favor the diesel direct over the diesel electric. The main difference and decisive factor in this case is the investment cost in the propulsion system, which is higher for the diesel electric concept than for the diesel direct concept

The stability calculations show that the barge GM-value meets the regulations in most cases. The necessity of a contra weight and the use of water ballast has been proven .Only in theoretical situation, a situation could occur where the barges Gm-value becomes less than 1.0 meter. It will however always be above the value of 0,5 meters which is demanded for container barges which transport containers in cell guides.

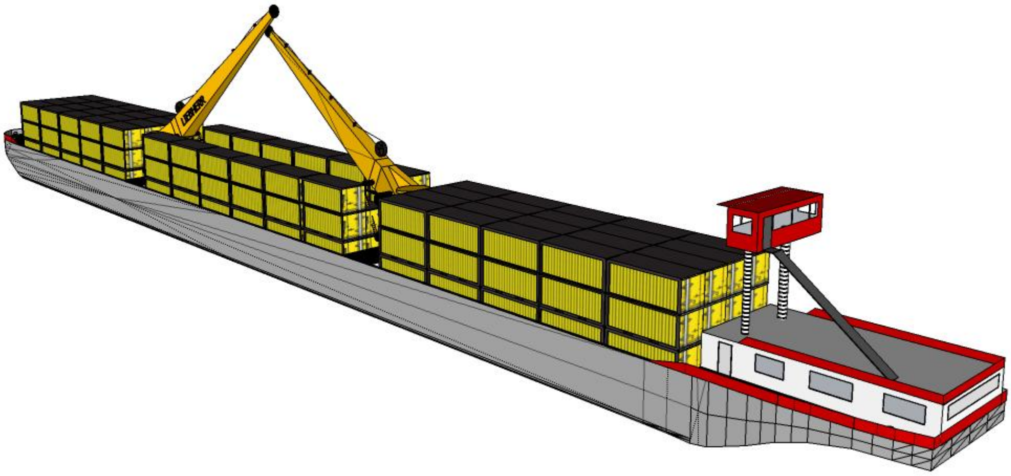


Figure 6.24 Developed inland barge(1)

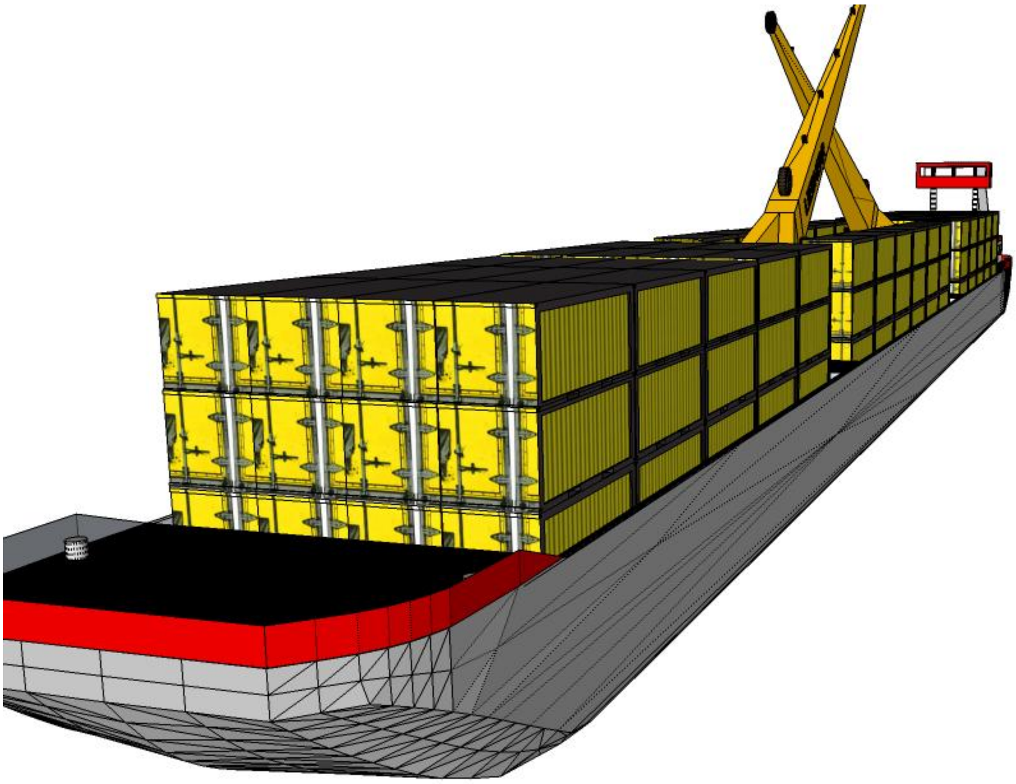


Figure 6.25 Developed inland barge(2)

7 Logistics and economic performance

This chapter will describe the logistical system in which the barges will operate. It will compare truck transport with the transportation of containers by barge on a variety of routes. First, the different logistic systems will be described.

7.1 Transport systems

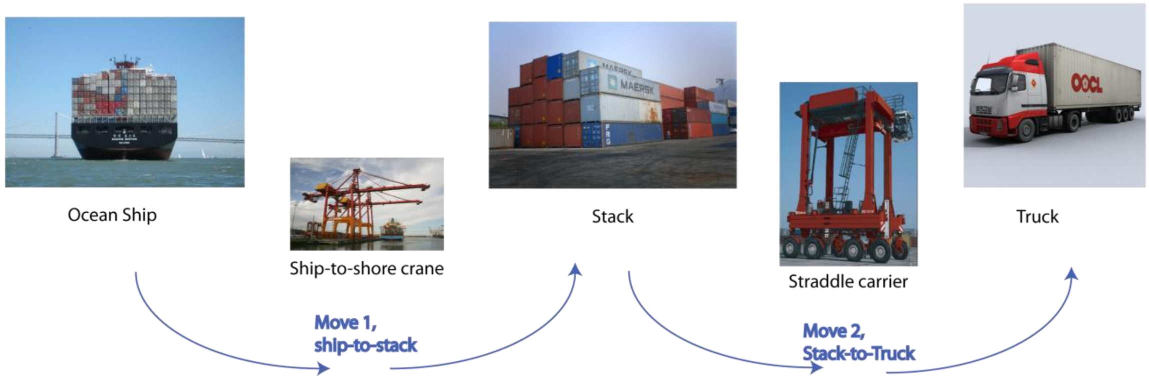


Figure 7.1 Overview truck logistic system

The transfer of a container from an ocean going vessel to a truck (and vice versa) requires two moves. The first one is from the container vessel to the stack. In fact, the container is lifted from the vessel to the quayside where it is transported to the stack. The company which runs the terminal has defines this as one move. The second move is the transfer of the container from the stack by means of for instance a straddle carrier to the truck. It is assumed that the truck is the final transportation mode.

In case of transport by barge, the logistic system becomes a bit more complicated. Figure 7.2 shows this.

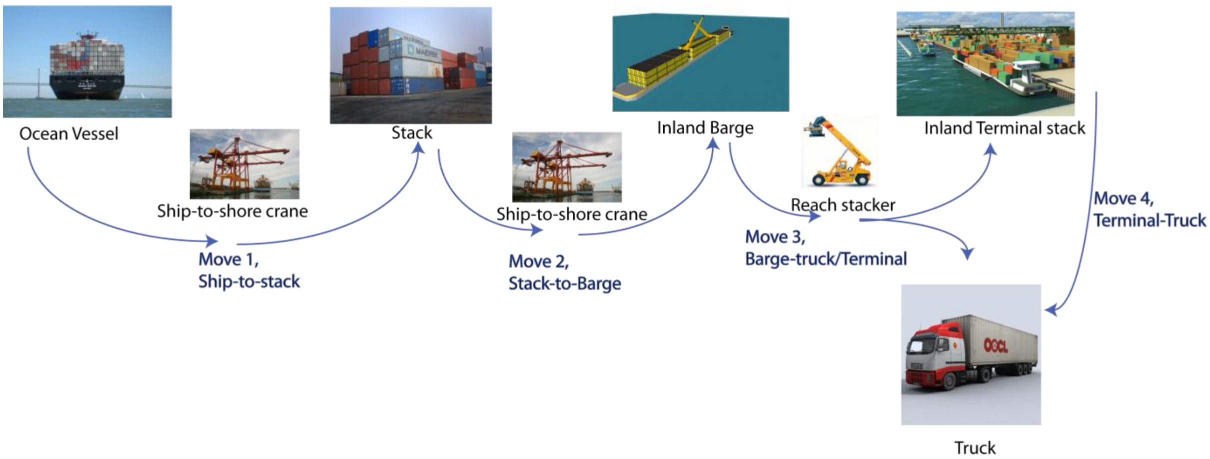


Figure 7.2 overview barge logistic system

Inland navigation is hardly ever the final transport mode. Transporting containers by barge results in extra intermodal moves which are often very expensive. The first move is the same as in figure 7.1. This move is therefore of no interest in the comparison between truck and barge transport. The second move, stack-to-truck or stack-to-barge, seems comparable but is not the same from a price point of view. There is a price difference between the transfer from the sea terminals stack to a barge or to a truck. It is estimated that the price for move two is 85 euro's for the move to truck and 95 euro's for the move to inland barge.

The third move is the transfer of the container from the inland barge to either the stack of the inland terminal of directly to the truck. The fourth move would be the transfer of the container from the stack of the inland terminal to the truck. In this thesis, it is assumed that the entire freight flow of an inland terminal will be placed in the stack for a while. From now on, reference will be made to move three as the transfer from inland barge to truck, through the stack of the inland terminal. The average price of such a transfer in 2001 was €29,8 (Michel Savy, 2001). Assuming an average price increase of 3%, the price in 2009 is €35 per move.

An important aspect for truck transport is the waiting time. The average waiting time for a truck visiting a terminal in Antwerp is one hour (Mobius, 2008). This is the time between the arrival at the terminal and the moment the truck leaves the terminal loaded or unloaded. It is assumed that a truck will need half an hour at an inland terminal. This is based on limited security measures at inland terminals and a decreased amount of paperwork. A delay due to congestion around Antwerp should be added as well. The delay depends on the route a truck drives and on which hour of the day the container is transported. The cost, resulting from this *congestion related delay* is therefore a variable. The influence of congestion on the total transport cost is not incorporated in the calculations.

Inland barges often encounter large delays in main ports due to low priority at terminals. The delay can be measured by calculating the average time per move for inland barges which transport containers. The average time per container move is tracked by inland shippers. For Antwerp, the so-called "port-laytime-index" (NL: havenverblijfindex) was about eight minutes in 2009. (CBRB, 2009).

Table 7.1 shows the time needed to load and unload an inland barge, given the index previously described. Assumed is an occupation rate of 1. The fifth column states "delay" whereas in fact in this column, the sailing time between the visited terminals in ports is included as well.

Bargetype	Capacity (TEU)	Port-time (hours)	(un)loading (hours)	Delay (hours)
Albert Canal	258	68.8	15.2	53.6
Hybrid	242	64.5	14.2	50.3

Table 7.1 Port time and delay

It has to be mentioned that the level of the port-laytime-index is probably influenced by small vessels which sail to many terminals with very small call sizes at each terminal. Larger vessels will have bigger call sizes which result in a higher priority at terminals. The time per move in a port is probably smaller then the port-laytime-index indicates. Since this difference cannot be quantified the generalized Port-laytime-index will be used. Calculations will show the influence of the delay on the transport price of the barge and the total revenues per year later on in this chapter.

7.2 Routes

Figure 7.3 shows the main structure of the transport routes. Freight will be transported from location A to C. Location A, Antwerp, is the origin or destination of all freight. Location C is the final destination of the transported containers. This location is not found near a waterway. So in case of transport by barge, end transport is needed by truck.

The situation when location B is the end location will be addressed as well. In such a situation, the container would be loaded or unloaded directly at a company.

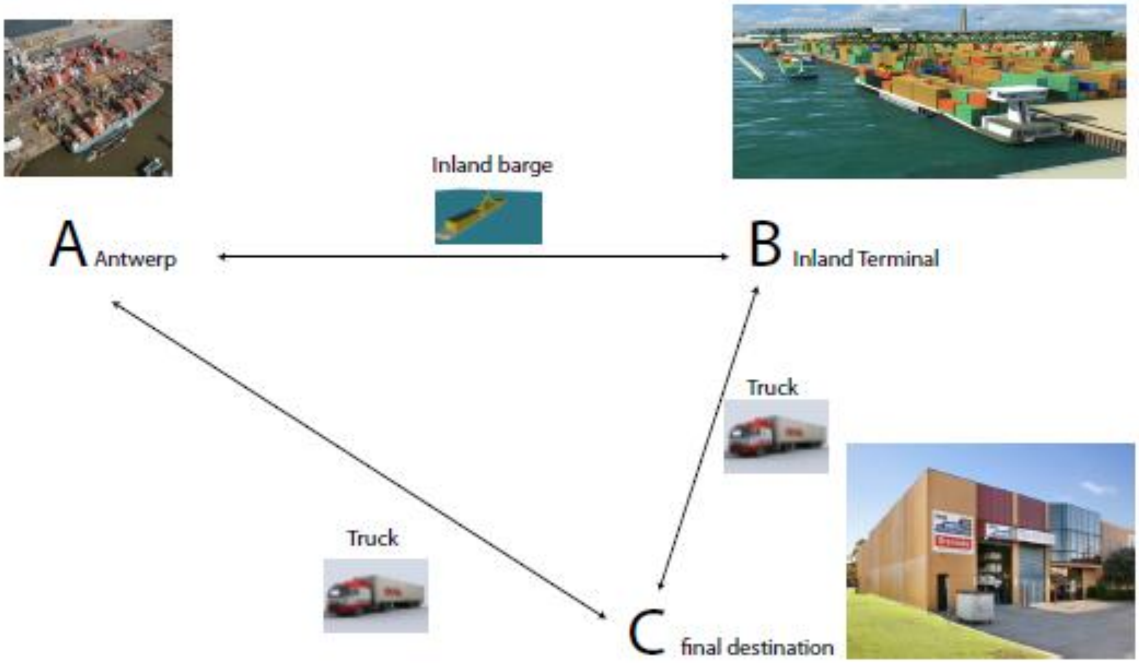


Figure 7.3 transport routes

The selected routes are shown in table 7.2. These routes have been chosen since they represent a variety of transport possibilities. The column "distance barge-truck" describes the transport distance by barge and the end-transport distance by truck. The column "distance truck" represents the direct transport distance by truck from Antwerp to the end destination.

Route	From	To	Via	Distance Barge-truck	Distance truck
R1	Antwerp	Turnhout	Grobbendonk	50 km/ 30 km	70 km
R2	Antwerp	Beringen	Meerhout	70 km/ 30 km	85 km
R3	Antwerp	Dusseldorf (GE)	Lanaken	125 km/ 110 km	215 km

Table 7.2 transport routes

7.3 Cost calculation formula's

This paragraph will describe in what way the cost of container transport is calculated. It will show the formula's for truck transport and for barge transport.

7.3.1 Truck transport

The cost of truck transport is based on a cost function from the Flemish freight model (Mint nv, K+P Transport consultants, 2009). The cost is function of time and distance.

$$C_{\text{truck}}\,(x,t) = 36.21t + 0.50x \qquad (6.40)$$

So in fact, a truck costs €36.21 per hour and €0.50 per kilometer[1)]. With this formula, the cost of transport by truck from A to C and from B to C can be calculated. It is assumed that the cost and price of truck transport are the same.

7.3.2 Barge transport

The cost of container transport by barge is based on the calculation done by NEA (NEA transportonderzoek, 2004). This calculation has been changed. The new build prices of the two barge types are shown in table 7.2.

	New Build price Albert Canal Barge	Hybrid Barge
Steel	€1.817.760	€1.817.760
Machinery	€704.751	€1.594.068
Propellers	€50.000	€72.000
Mooring winches	€18.000	€18.000
Deckhouse	€160.000	€160.000
Cranes	€1.200.000	€1.200.000
Spreader+additionals	€400.000	€400.000
Additional 20%	€870.102	€1.052.365
Total cost	€5.220.613	€6.314.193
Total Price	€5.742.674	€6.945.612

Table 7.2 Structure new build prices Albert canal barge and Hybrid barge

The cost for casco (steel) is based on a price of €1.164 per ton (staalprijzen.nl, 2009), including primer. Producing the casco is estimated to take 25 hours per ton at a price of €40 per hour. Including a factor of 1.2, the price per ton becomes €2.600.

The cost for machinery originates from chapter 6.

The cost of the propellers is based on a guideline from Wartsila of €20/ kW. Since the Albert canal barge has only 250 kW of installed power, the propellers would cost around €5000. It is assumed that the guideline is not correct for the Albert Canal barge (AC barge). The cost for the Hybrid barge’s propellers is expected to be correct. The price of the AC barge is assumed to be €25.000, about 30% lower than the hybrid barge since the amount of material needed to produce the propeller is significantly less.

The price of the mooring winches is based on prices from Van der Welde Marine systems (Van Hassel, 2008). The price of a winch is €9.000.

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1) The exact structure of this formula cannot be shown here since it is confidential.

The price of the deckhouse is based on the report from Van Hassel as well. For a small push barge, the deckhouse is estimated to cost €225.000. The deckhouse of the developed barges is installed on top of one or two cylinders which makes the air draft variable. The price of the deckhouse is therefore assumed to be €350.000.

The prices of the conventional Liebherr CBW cranes, the spreaders and the additionals originate from an email from the Liebherr Company. See appendix 7.1.

The calculation so far does not incorporate the costs of for instance a bowthruster, anchors, paint and a steering machine. It is therefore assumed that additional costs are 20% of the costs calculated so far. The profit of the yard is assumed to be 10%.
The cost of barge transport (C_{barge}) is equal to:

$$C_{\text{barge}} = C_{\text{cap}} + C_{\text{operational}} \tag{6.41}$$

$$C_{\text{operational}} = C_{\text{pers}} + C_{\text{fuel}} + C_{\text{R\&M}} \tag{6.42}$$

C_{cap} is the costs of capital. The barge will be financed with a mortgage and invested "own" money. The costs of lend capital is equal to the average invested amount (since it is being repayed during the mortgage period) times the interest rate, divided by the mortgage length in years and the amount of sailing days per year. The deprecation is included in C_{cap} as well.

The factor C_{pers} represents the costs of personnel. This number varies with the sailing schedule of the barge. As mentioned before in this report, sailing 24 hours per day results in a higher cost per hour then sailing 14 hours per day. The influence of the choice for a certain sailing schedule will be shown in the calculations later on. The implemented costs per hour are: €36.31 in case of 14 hours schedule, €61,26 when sailing 18 hours per day and €88,20 in a 24 hour sailing schedule.

The fuel usage of the barge and the corresponding fuel costs C_{fuel} depends on the fuel price and the fuel usage in each sailing condition. If a barge is sailing, it will use a different amount of fuel if compared to for instance loading and unloading. The fuel usage of the Albert Canal barge is different from the Hybrid barge. The price of Marine Gas Oil (MGO) is 500 euro/ton (Bunkerworld, 2009). The average demanded power and corresponding fuel consumption per sailing condition is shown in table 7.3

Barge Type → Sailing Condition↓	**Albert Canal Power demand**	**Albert Canal Fuel usage**	**Hybrid barge Power demand**	**Hybrid barge Fuel usage**
Sailing	250 kW	209 g/kWh	275 kW	215 g/kWh
Loading/unloading	500 kW	209 g/kWh	500 kW	215 g/kWh
Waiting	50 kW	209 g/kWh	50 kW	215 g/kWh
Hotel	35 kW	238 g/kWh	35 kW	238 g/kWh

Table 7.3 Power demand and fuel consumption

The cost for Repair and Maintenance ($C_{R\&M}$) is based on the NEA report. It is split into a sailing and non-sailing part as previously motivated in this report. The cost of this item has increased since the barge is likely to have more repair and maintenance due to the presence of the two conventional cranes. The cost for repair and maintenance is assumed to be €9 per hour in the non-sailing condition and €11 per hour when sailing or loading/unloading.

Table 7.4 gives an overview of the operational costs based on a 80% occupation rate. The difference in costs between the 14 and 24 hour sailing schedule is merely caused by the increased personnel costs.

	Albert Canal barge		**Hybrid Barge**	
Sailing hrs/day →	**14**	**24**	**14**	**24**
Route 1	€19	€25	€21	€26
Route 2	€20	€26	€22	€27
Route 3	€22	€29	€24	€30

Table 7.4 Operational costs

7.4 Pricing of Barge transport

From the previous paragraph, it is possible to calculate the cost of capital and the operational costs. A comparison of the price of truck transport with barge transport, the price of barge transport has to be calculated. Adding a margin of 5/10% on top of the calculated costs is not sufficient from an investment point of view. The prices in this chapter have been calculated to achieve a net present value of future earnings equal to the invested amount in a predefined period (payback period).

The margin on top of the total cost for the transport of containers by barge has to be calculated from an investment point of view. The Net Present Value (NPV) is calculated for a variety of situations. The NPV is calculated with the following formula:

$$NPV = \sum_{t=0}^{n} \frac{Free\ Cash\ Flow\ (t)}{(1+r)^t} \qquad (6.43)$$

So in fact, the NPV is the present value of future cash flows, discounted at a rate *r.* The factor *r* corrects the cash flows for inflation, interest and the risk taken in a project. In this thesis, the value of *r* is assumed to be 8%. Appendix 7.2 shows that if r is varied between 6 en 10%, the influence on the NPV is minor. The price for transport in case of a rate of 6% is €50 if the payback period is held constant at 7 years. If r is 10% the price becomes €53.

Table 7.5 shows the calculation method for the free cash flow. The turnover is calculated solely on the price of container transport times the transported amount of containers. The profit-tax is 30%. It is assumed that the mortgage period is 20 years and the residual value of the barges is 20% after 20 years.

1	Turnover
2	Operational costs
3=2-1	EBITDA
4	Depreciation
5=3-4	Operational result
6	Interest costs
7=5-6	Pre-tax result
8	Tax
9=7-8	Result after tax
10=9+4	Cash flow
11	Repayment
12=10-11	Free cash flow

Table 7.5 Cash flow calculation method

Figure 7.4 shows the development of the cash flow and the sum of the NPV over the length of the mortgage period. In this case, the mortgage is 70%, the barge sails 24 hours per day on route r3. The occupation rate is 80%. The price per transported container is €51.

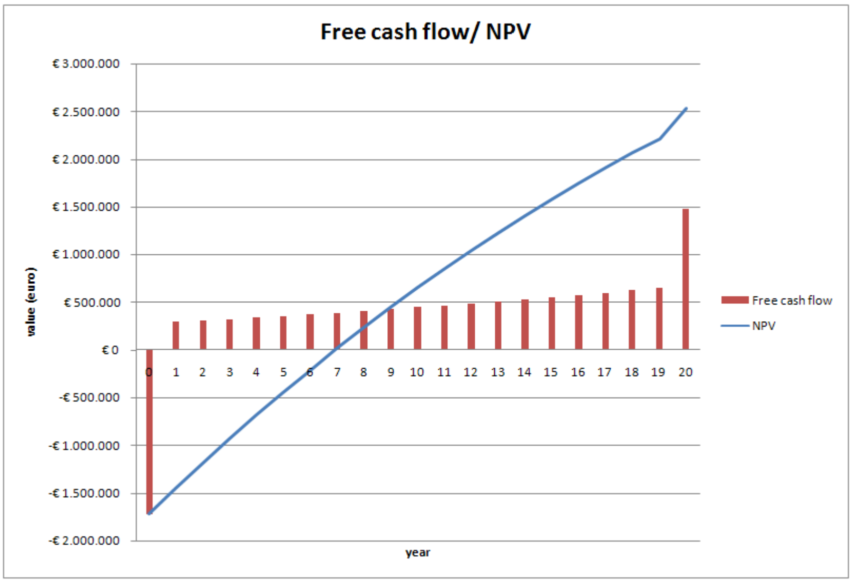

Figure 7.4 outcome NPV/cash flow calculation

In this figure, the two peaks in cash flow are caused by the acquisition of the barge in year zero and rest value of the barge at the end of year 20. An important aspect of figure 7.4 is the moment where the NPV is zero. This moment is called the *Payback period*. The preferred payback period is often defined by the main investor in a project. It depends on the behavior of the market in which the invested project has to operate.

The development of the cost-level and the price level over 20 years time is difficult to estimate. In the calculation done for figure 7.4 (see exact outcome cash flow calculation appendix 7.3), it is assumed that both the price and the costs increase with 3% per year.

In order to be able to compare the price of the different transport routes and barge types, the transport price has been calculated, assuming a Payback period of seven years.

The price for route 2 is not given in the following table(s). The price of transport on route 2 is always between the price for route 1 and route 3. It is therefore of no added value to show them in the tables 7.6 to 7.10.

	Albert Canal barge		**Hybrid Barge**	
Sailing hrs/day →	**14**	**24**	**14**	**24**
Route 1	€51	€44	€58	€49
Route 3	€60	€51	€70	€59
NPV				
Route 1	€2.563.000	€2.666.000	€3.060.000	€3.259.000
Route 3	€2.612.000	€2.553.000	€3.188.000	€3.682.000

Table 7.6 Price calculation AC/H barge

Table 7.6 shows the outcome of the price calculations of a barge, financed for 70% by a mortgage, sailing at an occupation rate of 80%. The amount of transported containers is in the range of 19000-23000 TEU/year when sailing 14 hours per day, and in the range of 33000 to 40000 when sailing 24 hours per day.

The price differences are quite significant. The differences in price based on the routes can simply be explained by the differences in length of the routes. The difference in price for the 14 and 24 hour sailing schedule is remarkable. Table 7.4 showed that the operational costs for the 24 hour schedule were higher than the 14 hour schedule. The difference in price level can be explained by the fact that the total turnover is much larger in case of the 24 hour sailing schedule. This is a result of the increase in the amount of transported containers. To achieve the preferred return, or NPV, the 24 hour sailing schedule results in a lower margin and thus a lower total cost.

If the two barges are compared with respect to the total NPV, the Hybrid barge should be preferred. This is remarkable since the investment and the operational costs are larger than those of the Albert Canal barge. The increased investment and higher operational costs result in a higher price to achieve the preferred payback period. The margin between the costs and the price increases over time. This is a result of the assumption that both the cost and the price increase with three percent per year. Three percent per year is equivalently 80 percent over 20 years. It is almost impossible to say something about the price and cost level of the transport of container via inland shipping over 20 years. These numbers are therefore unreliable on the long term. Figure 7.5 shows the development of the cash flow and NPV of both barge types over time.

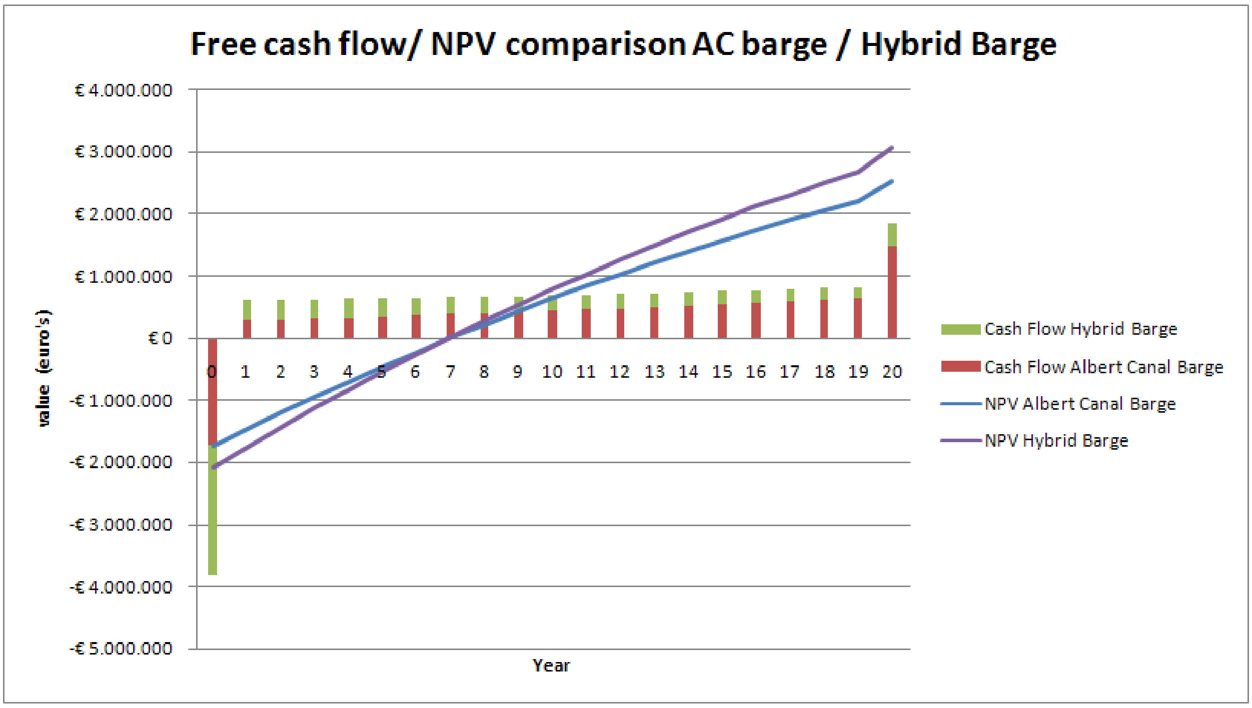

Figure 7.5 Comparison Cash flow

This figure shows that the demand for a higher cash flow (for the hybrid barge) results in a steeper increase of the NPV in 20 years time.

	Albert Canal barge		**Hybrid Barge**	
Sailing hrs/day →	**14**	**24**	**14**	**24**
Route 1	€59	€49	€69	€54
Route 3	€59	€57	€81	€64
NPV				
Route 1	€3.760.000	€4.000.000	€4.600.000	€4.520.000
Route 3	€3.785.000	€3.940.000	€4.610.000	€4.690.000

Table 7.7 50% mortgage

Table 7.7 shows the outcome of the price calculation if the mortgage rate is reduced to 50%. The price of transport is increased by €6/€9 to achieve the same payback period. This is a result of the increased invested amount of “own” money. The NPV after 20 years increases with respect to the 70% mortgage situation, since the interest costs and repayments are significantly lower.

	Albert Canal barge		**Hybrid Barge**	
Sailing hrs/day →	**14**	**24**	**14**	**24**
Route 1	€46	€41	€53	€45
Route 3	€54	€48	€62	€53
NPV				
Route 1	€1.550.000	€1.653.000	€1.820.000	€1.910.000
Route 3	€1.599.000	€1.680.000	€1.840.000	€1.960.000

Table 7.8 Payback period of 10 years

The influence of the payback period on the transport price can be seen in table 7.8. The reduced payback period results in lower transport prices. The need for margin on top of the operational cost is reduced. The reduction is between €3 and €6. The NPV after 20 years is reduced significantly. Figure 7.6 shows the influence of the payback period on the transport price.

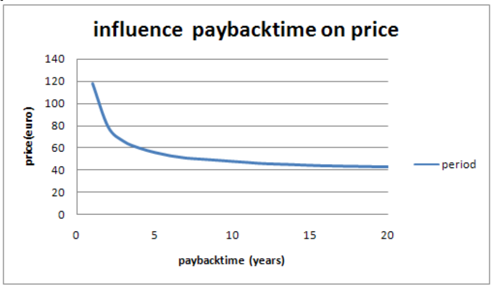

Figure 7.6 payback period variations

Table 7.9 shows the influence of occupation rate on the transport price. It has to be mentioned that in case of the 100% occupation rate, the amount of transported containers varies between 23.000 and 40.000. In case of an occupation rate of 20%, the amount of transferred containers varies between 11.000 and 29.000. Since these amounts vary significantly, it can be expected that they have significant influence on the transport price. Table 7.9 confirms this.

Occ.rate 100%	**Albert Canal barge**		**Hybrid Barge**	
Sailing hrs/day →	**14**	**24**	**14**	**24**
Route 1	€50	€43	€58	€48
Route 3	€57	€49	€66	€54
Occ.rate 20%	**Albert Canal barge**		**Hybrid Barge**	
Route 1	€68	€59	€80	€66
Route 3	€102	€88	€121	€99

Table 7.9 influence occ.rate on transport price

The differences in transport prices are significant. The reduction in transport price in case of a fully used barge is limited, €1 to €4. The transport increases significantly in the occupation rate drops to 20%. The prices increase with €15-€51.

All calculations done are based on an average port-time per move of eight minutes (CBRB, 2009). Table 7.10 shows the calculated prices of container transport if the average port time is reduced to 4 minutes. Decreasing port times result in decreased round trip time and thus an increased amount of transported containers per year.

4 minutes port time	**Albert Canal barge**		**Hybrid Barge**	
Sailing hrs/day →	**14**	**24**	**14**	**24**
Route 1	€34	€29	€39	€33
Route 3	€42	€37	€49	€41
NPV				
Route 1	€2.667.000	€2.598.000	€3.123.000	€3.564.000
Route 3	€2.506.000	€2.870.000	€3.050.000	€3.280.000

table 7.10 4 minutes port time per move

The following figure shows the influence of a variety of parameters on the price level. In fact, it is an overview of the previously given tables. The figure is based on the price level when transporting containers with the Albert canal Barge on route r3, financed by a 70% mortgage, 8 minutes per move in main ports, and a payback period of 7 years.

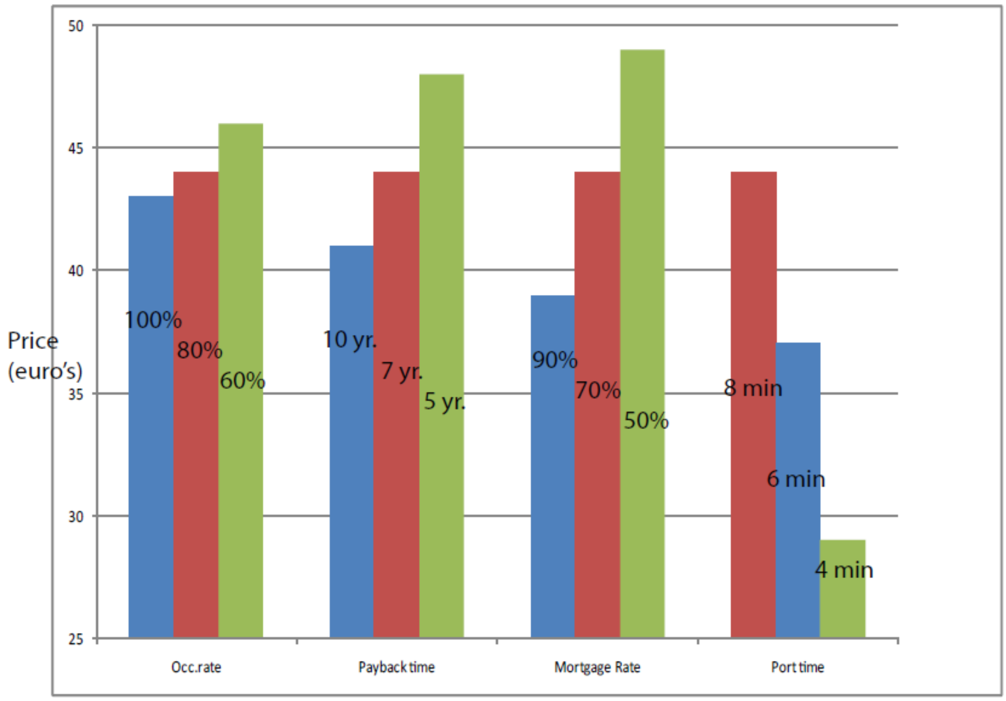

Figure 7.7 Overview price calculations

For every column, only one variable has been changed from the "standard" outcome of €44. It becomes clear that the occupation rate has minor influence on the price as long as it is above 60%. The influence of the average time per move in sea ports is substantial. A reduction in the price can be accomplished if the time per move is reduced to four minutes. In such a case, the barge is waiting for only ten hours in a main port instead of over 40 hours. The amount of roundtrips increases significantly. The corresponding amount of containers increases from 33769 to 49131 TEU per year.

The price of forty foot container transport can be calculated by doubling the corresponding cost per TEU. The capacity of the barge is reduced by a factor 2 and the price must therefore go up by the same factor.

7.5 Price comparison of transport modes

This paragraph will compare the price of transport from the stack of main terminals to the end destination of the three previously described routes. Table 7.11 shows the price of container transport for the Albert canal barge (AC barge), the Hybrid barge and the price for truck transport. The price is based on an occupation rate of 80%, a payback period of 7 years, a mortgage rate of 70% and 8 minutes per move in main ports.

	TEU					FEU			
Route	**AC Barge** *14hr*	*24hr*	**Hybrid barge** *14hr*	*24hr*	**Ctruck**	**AC Barge** *14hr*	*24hr*	**Hybrid barge** *14hr*	*24hr*
R1	€241 (+20)	€234 (+14)	€249 (+29)	€239 (+19)	**€220**	€292 (+72)	€278 (+58)	€308 (+88)	€288 (+68)
R2	€244 (+3)	€236 (-5)	€250 (+9)	€240 (-1)	**€241**	€298 (+58)	€282 (+41)	€310 (+89)	€290 (+49)
R3	€363 (-59)	€354 (-68)	€373 (-49)	€361 (-61)	**€422**	€422 (-)	€404 (-18)	€442 (-)	€420 (-2)

Table 7.11 cost of transport worst case scenario

This table is referred to as a "worst case scenario" since no possible advantages which the barge could have, are incorporated into the price calculations.

From this table, it becomes clear that transporting a container by a barge over a short distance is a challenge. On route 1, truck transport should be preferred over barge transport from a price point of view. The trend in pricing is clear. Barge transport can result in a price advantage if the transport distance by barge increases. The differences in price are minimal on route r2.

Table 7.11 shows the outcome of price calculations for the transport of a Forty foot Equivalent Unit (FEU) as well. The barges can no longer compete on route two with truck transport. The third route still shows a price advantage for barge transport if the container is transported with the Albert canal barge. The advantage TEU transport has, has however been diminished. In fact, on the shortest route r1, the difference between truck transport and transport by barge can be as much as 88 euro's (Hybrid barge), or equivalently 29%.

Figure 7.8 and 7.9 show the structure of the calculated prices on the different transport routes. Figure 7.8 shows the price structure on route r2 and 7.9 on route r3. The cost structure of the transport of a TEU, a FEU and transport by truck is shown.

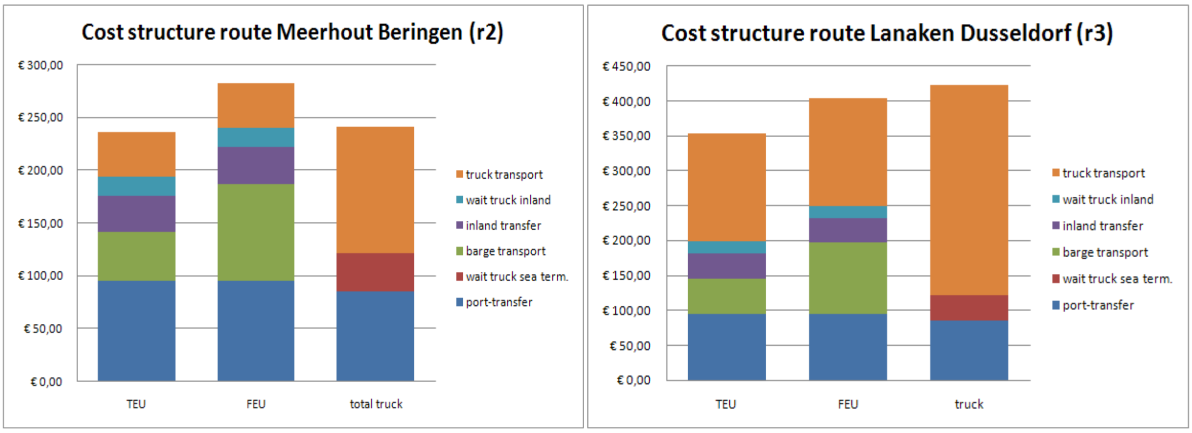

Figure 7.8 and 7.9, cost structure on route r2 and r3

Figure 7.8 shows the influence of the increased price for barge transport on the total price. A TEU can compete with truck transport, a FEU cannot. The costs of intermodal transfers are significant and a threat to the competitiveness of the developed inland barge.

From figure 7.9, it becomes clear the price for truck transport outnumbers the price for barge transport. The price for end-transport is of the same size as the cost for barge transport, including the intermodal shifts.

Table 7.12 shows the outcome of the price calculations if the average time-per-move is reduced to four minutes and if the intermodal costs are reduced by 25%. It becomes clear that the competitiveness of the barges increase significantly. The transport of FEU's on route r1 remains a challenge but is possible. It has to be considered that a barge will always transport TEU's and FEU's. The transport of FEU's could therefore be compensated by the profit made with the transport of TEU's.

	TEU					FEU			
Route	**AC Barge** ***14hr***	***24hr***	**Hybrid barge** ***14hr***	***24hr***	**Ctruck**	**AC Barge** ***14hr***	***24hr***	**Hybrid barge** ***14hr***	***24hr***
R1	€191 (-29)	€186 (-34)	€196 (-24)	€190 (-30)	**€220**	€225 (+3)	€215 (-7)	€235 (+15)	€223 (+3)
R2	€194 (-47)	€188 (-53)	€198 (-43)	€191 (-50)	**€241**	€231 (-10)	€219 (-22)	€239 (-2)	€225 (-16)
R3	€312 (-110)	€307 (-115)	€319 (-103)	€311 (-111)	**€422**	€354 (-68)	€344 (-78)	€364 (-58)	€352 (-70)

Table 7.12 cost of transport with reduced time-per-move and terminal costs

The most optimal situation would exist if the demand for end transport disappears. It becomes clear from the cost structure in figure 7.8 and 7.9 that a significant cost-advantage can be obtained. The cost of the terminal in Antwerp has been reduced by 25% en the average time per move is assumed to be 6 minutes, a reduction of 25%.

The transport routes have been adapted for table 7.13. R1 is to Grobbendonk, R2 to Meerhout and R3 to Lanaken. The transport distance by barge is assumed to be equal to the distance for truck transport. This is acceptable since the highway E313 follows the shape of the Albert canal.

The calculated prices in table 7.13 show a striking difference with truck transport. The full potential of the developed barges is shown here. In all cases, the transport of containers, TEU's and FEU's, is cheaper than the transport by truck. On the route to Lanaken, the difference can be as large as €181.

	TEU					FEU			
Route	**AC Barge** ***14hr***	***24hr***	**Hybrid barge** ***14hr***	***24hr***	**Ctruck**	**AC Barge** ***14hr***	***24hr***	**Hybrid barge** ***14hr***	***24hr***
R1	€114 (-77)	€108 (-83)	€119 (-72)	€111 (-80)	**€191**	€157 (-34)	€145 (-46)	€167 (-24)	€151 (-40)
R2	€116 (-103)	€110 (-109)	€122 (-93)	€113 (-106)	**€219**	€161 (-58)	€149 (-70)	€173 (-46)	€155 (-64)
R3	€122 (-174)	€115 (-181)	€129 (-167)	€119 (-177)	**€296**	€173 (-123)	€159 (-137)	€187 (-109)	€167 (-132)

Table 7.12 cost of transport without end-transport

The trend in calculated prices is clear. The developed barges have to achieve price reduction in order to be able to compete with truck transport. The worst case scenario shows a significant price advantage for truck transport on short distances. This confirms expectations and the fact that truck transport is nowadays favored over barge transport because of these large price differences.

It is however possible to create a significant price advantage for the developed barges. Reducing the average time-per-move is a good measure. If the need for end-transport disappears, a major price advantage can be obtained.

8 Evaluation

The calculated prices in chapter seven show a clear trend. Competing with truck transport is a challenge for the developed barges, or in fact for the entire inland shipping sector. The designed barges create a variety of opportunities to reduce the total cost of container transport. These opportunities should be considered before any final conclusions on the competitiveness of the designed barges can be made. This chapter evaluates and discusses the outcome of the price calculations and the expected logistics performance of the developed barges.

Price of transport

Two different situations should be considered. The first one is the transport of containers by barge with end-transport by truck. The second situation represents the transport of a container which is delivered directly to a company by the developed barge.

In case of the first situation, transporting TEU's over the Albert canal can be competitive with truck transport. Calculations show that this is possible from a minimal sailing distance of 50 km (including 30 km end-transport). The competitiveness of the developed barges can easily be increased if the intermodal costs are reduced. This should be possible since the developed barges are capable of doing a part of the terminal processes autonomously.

Transporting FEU's by barge is a more difficult challenge since the cost of transport by barge doubles. The total stack-to-door, transport prices increases by 10-15%. The comparison of FEU transport with truck transport is essential since trucks often transport 40 or 45 foot containers. The need for price reductions increases therefore with the transport of FEU's by barge. The worst case scenario results in a price difference on the shortest route r1 of €58.

The difference in price can easily be reduced if for instance the average time-per-move is reduced to 4 minutes. This reduces the previously mentioned difference of €58 to €28. If the intermodal transfer costs are reduced by 25%, the price difference between barge and truck transport becomes zero. For barge transport, competing with truck transport is only possible if multiple cost reductions are achieved.

The second situation which has to be mentioned occurs if the developed barge is able to load or unload a container directly to a company's location. The cost of end-transport of for instance a TEU on route r1 is more than 40% of the total stack-to-door transport price. The calculations in chapter 7 show that this situation gives significant price advantages to the developed barges.

It has to be mentioned that the delays which trucks encounter due to congestion near Antwerp have not been incorporated into the calculations. Given a cost of about €45 per hour due to congestion, a 15 minute delay can already have significant influence on the competitiveness of truck transport.

Another aspect which has not been incorporated into the price calculations is the total transport time. One could say that expensive freight devaluates over time and that the devaluation and the difference in total transport time should be transferred into a price advantage for truck transport. This has not been done because these costs are not easily quantifiable and it can be questioned whether such these costs are in fact really seen as costs by the owner of the goods.

A third aspect which has not been incorporated into these price calculations are the external costs. These external costs are not real costs yet, they might become in the future. It is likely that this will benefit the inland navigation sector.

Terminal processes

It has to be mentioned that the behavior of the (inland) terminals with respect to the developed barges is unknown. The internal terminal process has to be adapted to let the barge operate optimally. The developed barges can create opportunities for the terminals.

The developed barges are able to load and unload containers autonomously, but depend on the terminal for the supply of containers. If barge calls the terminal a few hours in advance to announce its planned arrival, the terminal can already locate the containers near the quay. The terminal can proceed with the loading and unloading containers from ocean going vessels while the barge is handling these containers without the necessity of other terminal facilities and services. When the barge leaves the terminal, the unloaded containers can be placed in the stack at any particular moment which the terminal suits.

The developed concepts aim to deliver large batches to sea terminals and to offer them grouped by destination and end modality. From a terminal's point of view, it is important to know when a container arrives, where it is going and what the next transport mode will be. The chance for success increases if the information flow towards the sea-terminal is optimized.

The price of transport is the lowest if the barge is able to sail 24 hours per day. This is possible since the terminals operate on a 24 hour basis. If the barge loads containers directly from a company located near the Albert canal, these containers have to be placed within the operating range of the barge. The necessity of the presence of equipment and personnel from the company would then disappear, reducing costs and increasing opportunities for the company.

Albert canal Barge / Hybrid barge

Two barges have been developed whose acquisition price is significantly different. The resulting total transport prices differ by three to four percent. It can be thus be questioned whether such a difference favors the Albert canal barge over the Hybrid barge. The total transport price is somehow misleading. The prices for transport by barge should be compared instead of the total transport price. The differences between the prices of barge transport vary between 10% and 15%.

9 Conclusions and Recommendations

9.1 Conclusions

The transport of containers from Antwerp to the hinterland is often done with trucks. Congestion and pollution are two important reasons to transport containers with other transport modes than road transport like inland navigation and rail transport. There are however many reasons why companies prefer truck transport over barge transport. This research has resulted in an alternative for container transport within the Economic Network Albert canal. An economically and logistically feasible transport concept for the transport of containers over the Albert canal has been developed.

One of the most important parameters of the developed barges is the transport capacity. Research has shown that scale advantages can be obtained under the condition that the transfer rate of the loading & unloading equipment is significant. The capacity of the barges is limited by the maximum dimensions of the barges. The locks along the Albert canal limit the dimensions of the barge to 135*11,45*3,5 (L*B*T) meters.

A variety of loading & unloading equipment types have been compared on weight, transfer rates, dimensions and price (a.o.). Most concepts have significant disadvantages compared with the conventional, CBW crane. The conventional crane has a significant transfer rate, is technologically feasible and has a large operation range. These are important and decisive parameters in the choice for the conventional crane as the loading & unloading equipment for the developed barges.

The initial operation range of the developed barges was the Albert canal. To achieve the maximum speed of 12 km/h on the Albert canal, 300 kW of propulsive power has to be installed. This is nowhere near the demanded power for propulsion if the barges operating range is extended to instance the river Rhine. A higher maximum speed, combined with the influence of currents and rapids, results in a demanded power of 1.800 kW.

The difference in demanded propulsive power has resulted in a diesel electric propulsion system for the Albert canal barge and a diesel direct propulsion system for the Hybrid barge. The transport capacity of the Albert canal barge is 258 TEU. This is 16 TEU more than the Hybrid barge. The increase in capacity is a result of the choice for diesel electric as a propulsion system. The machinery space bulkhead is situated in such a way that an extra row of containers can be placed. A diesel electric system is more expensive per kW, but given the increase in transport capacity, the diesel electric system is economically feasible in case of the Albert canal barge.

Economic performance calculations have been executed to compare the price of transport of the developed barges with truck transport on a variety of routes. These calculations clearly show the necessity of cost reductions if the barges sail from terminal to terminal and cannot claim any cost advantages, despite the presence of the cranes. The developed barges can in fact have a price disadvantage of up to €88 per transported FEU on the route to Turnhout via Beringen (r1).

The disadvantage can be changed into a cost advantage of up to €46 for the same barge on the same route if the need for end transport disappears and the terminal costs in Antwerp are reduced with 25%. If the transport distance increases, the price of transport, to for instance Lanaken, can be €181 cheaper than the price of truck transport. The presence of the need for end-transport is in fact the main threat to the success of the barge.

The external costs are not included in the cost-calculations. If these costs will be included by means of governmental regulations (e.g. taxes), it is likely that the inland navigation sector as a whole, and thus the developed barges, will benefit since the external cost of inland shipping are lower than the costs of truck transport.

The availability of freight is uncertain. The containerization rate of freight transported by truck is unknown. It is therefore not possible to quantify the potential (container) transport market. The developed barges will add a significant amount of capacity to the existing container transport market within the Economic Network Albert canal. The level of industrialization around the Albert canal and the possibilities of the developed barges should however create a sufficient demand for transport to make the implementation economically feasible.

9.2 Recommendations

The recommended subjects for future research are:

1) *The validation of the new build price of the developed barges.* Assumptions were necessary to calculate the new build price of the developed barges. These assumptions were based on other reports instead of for instance contacts with shipyards. The quality of these assumptions could therefore be questioned and should be improved with further research.

2) *The quantification of the potential container freight market*. The quantity of containers transported nowadays over the Albert canal is known. The potential market does however exceed the existing inland navigation sector. The developed barge can compete with truck transport. The truck transport freight market is known, including origin-destination data. The missing link in this data is the containerization rate of the freight transported by truck. It is not known whether freight is being transported in a "normal" truck or in a container. If this data can be obtained, the potential transport market for the developed barges can be quantified.

3) *Obtaining commitment from companies and terminals along the Albert canal*. The implementation of the developed barge will depend on the commitment of companies along the Albert canal, or companies involved in transport over the canal. The functioning of the barge will partly depend on the demands of companies and terminals. It is yet unknown to what extend terminals are willing to adapt their process in order to let the barge operate optimally and what the influence on the terminal price will be.

   Companies which are able and willing to shift their demand for transport capacity to the Albert canal will have to be identified. This has to be done in order to "guarantee" the supply of containers to the developed barges in the start-up period.

4) *Creating a benchmark from the cost/price structure of an existing inland barge.* The cost structure of the developed barges has not yet been compared with existing, comparable inland barges. This has to be done to validate the cost calculations in this report. It will create insight in the position of the developed barge with respect to existing inland barges from a cost point of view.

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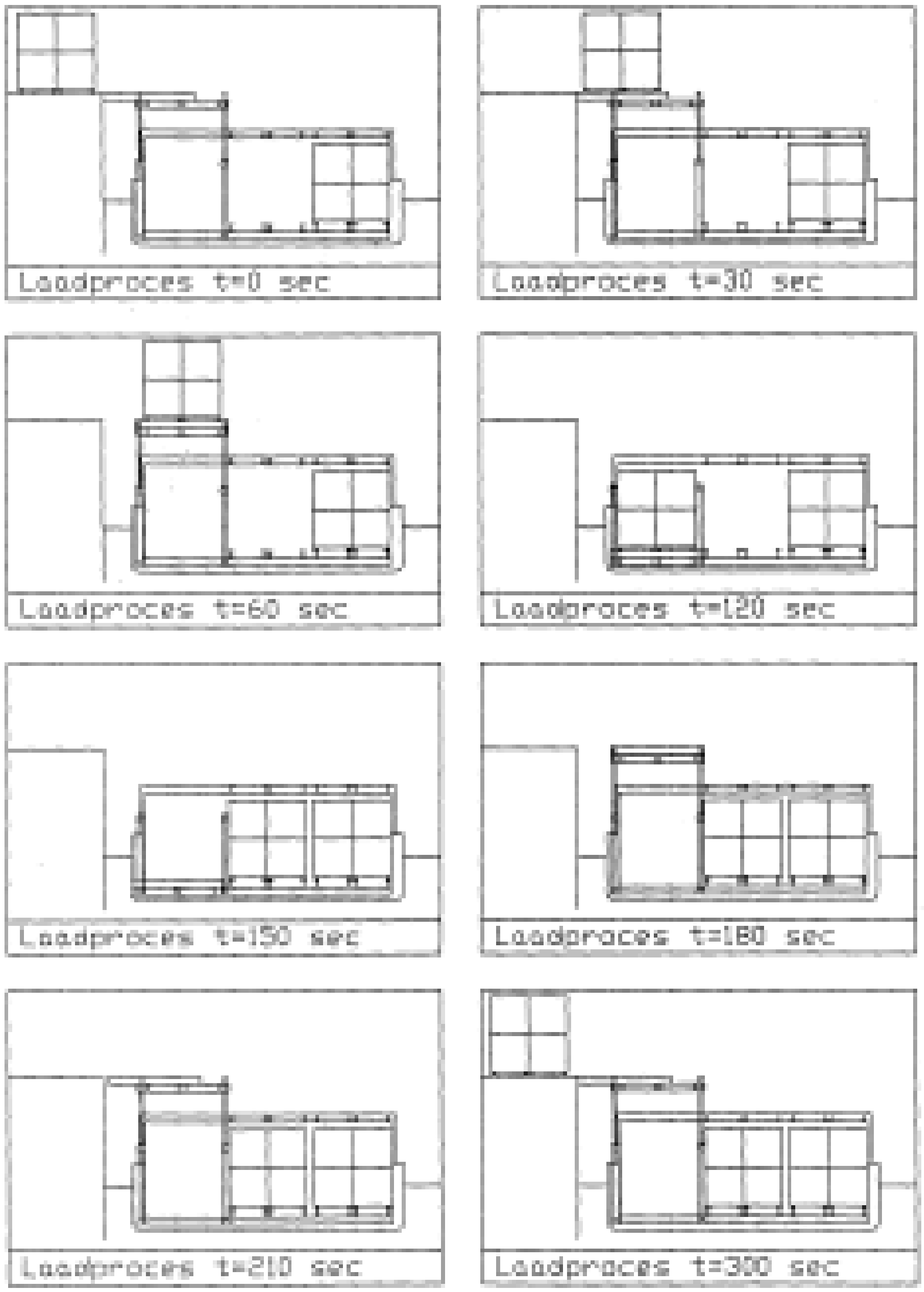
Appendices

Appendix 3.1 Container flows

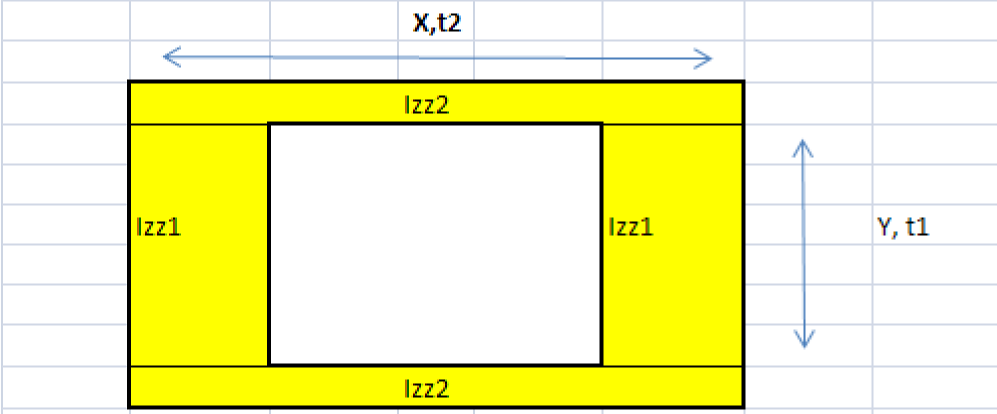
CONTAINERVERVOER

RELATIES		Trafiek 2007					
		Geladen containers			Ledige containers		
	a.s.	ton	a.l.	TEU	ton	a.l.	TEU
Antwerpen-Antwerpen	4	203	4	21	26	1	12
Amsterdam-Meerhout	91	47.123	91	6.771	105	1	42
Antwerpen-Avelgem	1	180	1	17	-	-	-
Antwerpen-Beringen	83	10.817	77	1.285	408	21	150
Antwerpen-Born	12	11.469	11	583	260	6	113
Antwerpen-Genk	333	270.520	319	17.948	14.685	230	5.580
Antwerpen-Herent	-	-	-	-	-	-	-
Antwerpen-Luik	177	51.015	171	4.265	9.254	151	3.775
Antwerpen-Meerhout	819	465.518	595	47.633	53.281	422	21.455
Antwerpen-Mol	88	13.873	79	1.277	1.034	47	427
Antwerpen-Schoten	332	88.900	225	5.442	12.106	129	6.261
Antwerpen-Seraing	8	3.069	7	187	361	7	156
Antwerpen-Stein	197	12.811	99	734	9.101	174	3.968
Antwerpen-Zeebrugge	-	-	-	-	-	-	-
Avelgem-Schoten	1	95	1	5	-	-	-
Basel-Antwerpen	-	-	-	-	-	-	-
Basel-Schoten	-	-	-	-	-	-	-
Beringen-Antwerpen	67	3.945	27	261	2.983	62	1.258
Beringen-Genk	-	-	-	-	-	-	-
Beringen-Mol	50	82	2	6	561	12	160
Born-Antwerpen	12	12.417	12	849	55	3	18
Genk-Antwerpen	335	203.066	284	11.292	32.410	306	14.056
Genk-Beringen	1	112	1	18	18	1	6
Genk-Duitsland	6	1.100	1	42	727	5	362
Genk-Luik	1	938	1	34	-	-	-
Genk-Meerhout	-	-	-	-	-	-	-
Genk-Rotterdam	6	1.869	4	90	108	2	50
Genk-Schoten	2	134	2	13	-	-	-
Genk-Seraing	-	-	-	-	-	-	-
Genk-Stein	1	-	-	-	30	1	12
Luik-Antwerpen	187	96.141	183	4.933	8.684	167	3.860
Luik-Genk	2	-	-	-	191	2	88
Luik-Schoten	2	100	2	4	-	-	-
Meerhout-Amsterdam	42	2.338	31	344	4.602	30	2.030
Meerhout-Antwerpen	922	672.466	609	39.930	104.872	591	46.036
Meerhout-Beringen	-	-	-	-	-	-	-
Meerhout-Born	-	-	-	-	-	-	-
Meerhout-Brussel	-	-	-	-	-	-	-
Meerhout-Duitsland	10	-	-	-	1.526	10	714
Meerhout-Genk	11	-	-	-	891	11	391
Meerhout-Gent	1	-	-	-	96	1	48
Meerhout-Luik	1	-	-	-	60	1	30
Meerhout-Mol	1	350	1	30	-	-	-
Meerhout-Rotterdam	276	86.514	198	8.926	16.949	168	7.424
Meerhout-Schoten	15	60	1	4	1.611	15	752
Meerhout-Stein	1	-	-	-	46	1	28
Meerhout-Zeebrugge	32	763	2	77	3.262	33	1.438
Mol-Antwerpen	83	13.980	65	738	2.015	58	906
Mol-Beringen	6	560	6	41	8	1	3
Mol-Schoten	2	236	2	35	-	-	-
Rotterdam-Genk	10	12.429	9	445	353	2	141
Rotterdam-Luik	1	911	1	41	-	-	-
Rotterdam-Meerhout	339	181.445	337	28.601	338	4	138
Rotterdam-Schoten	177	137.248	158	15.342	473	7	198
Rotterdam-Seraing	1	816	1	32	-	-	-
Rotterdam-Stein	2	1.312	2	50	18	1	8
Schoten-Antwerpen	301	114.395	248	7.514	4.708	85	1.976
Schoten-Avelgem	2	-	-	-	24	2	12
Schoten-Genk	1	40	1	8	-	-	-
Schoten-Meerhout	1	79	1	2	-	-	-
Schoten-Rotterdam	176	132.664	175	15.765	15	1	4
Seraing-Antwerpen	2	2.677	2	83	48	1	22
Stein-Antwerpen	218	88.712	213	5.770	845	35	348
Stein-Genk	2	600	2	44	30	1	12
Wijgmaal-Antwerpen	2	200	1	40	320	1	128
Willebroek-Schoten	1	150	1	7	-	-	-
Zeebrugge-Antwerpen	1	-	-	-	10	1	5
Zeebrugge-Meerhout	15	5.054	14	564	171	1	84
Zeebrugge-Schoten	11	2.009	11	184	-	-	-
Overige	-	-	-	-	-	-	-
TOTAAL	**5.484**	**2.753.505**	**4.291**	**228.327**	**289.679**	**2.812**	**124.685**

Appendix 4.1 Rollerbarge



Appendix 4.2 Calculation Gantry Crane Beam

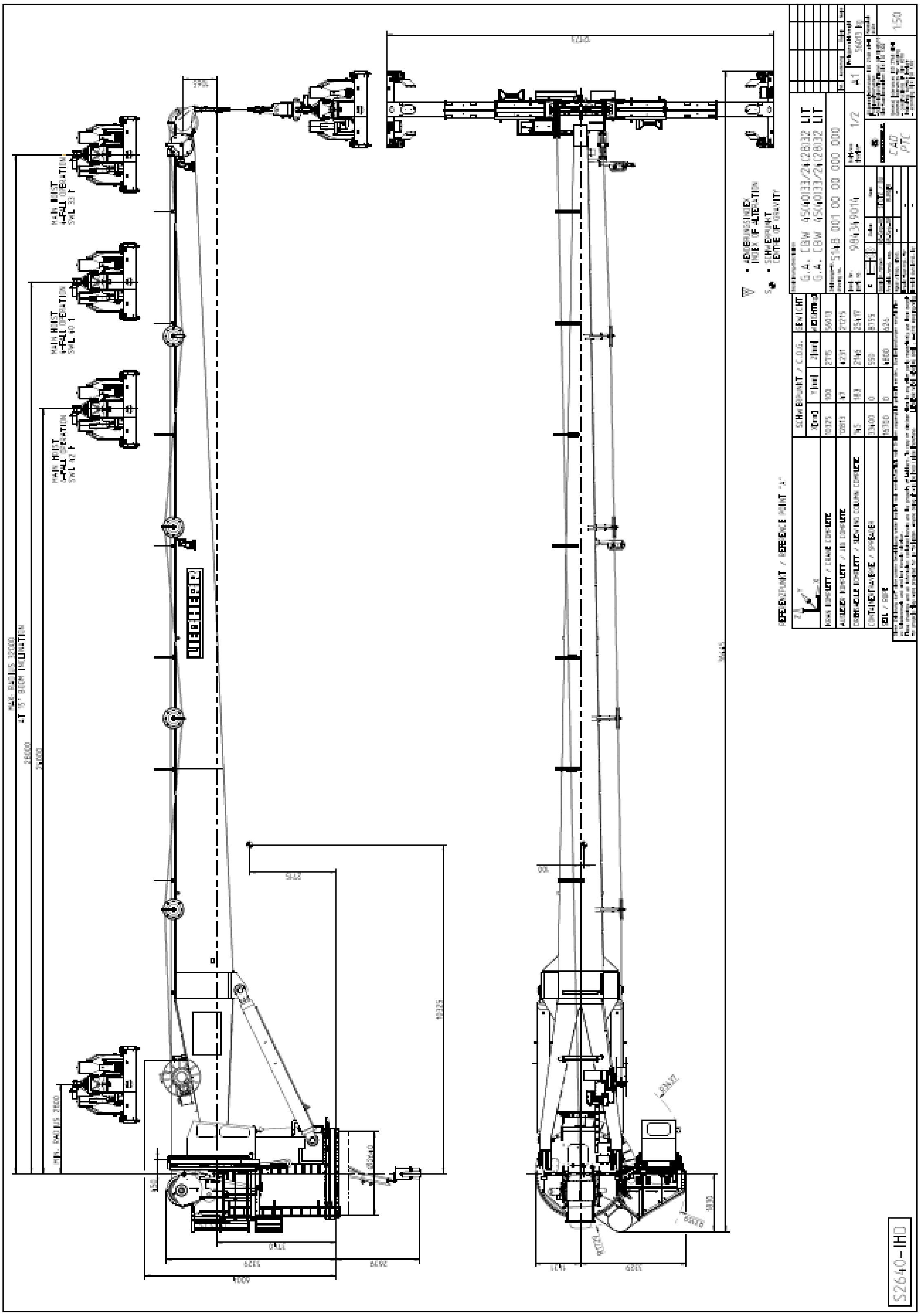


x(mm)	700	beam	0,065	m2
y (mm)	500	gewicht	5,07	ton
t1(mm)	60			
t2(mm)	50			

izz1	6,25E+08	mm4		
izz2	2,65E+09	mm4		
izztot	6,56E+09	mm4		
cont gewicht	30000	kg		
G	9,81	m/s^2	simga_max	235
Outreach	10	m		
moment	2,94E+09	Nmm		
sigma	1,35E+02	N/mm2		

$$sigma = \frac{M * y}{Izz}$$

Appendix 6.1 CBW Crane



Appendix 6.2 Hydrostatic calculation preliminary shape

Trim:	0.000	m											
Draft	Lwl	Bwl	Volume	Displ.	LCB	Cb	Am	Cm	Aw	Cw	LCF	Cp	S
m	m	m	m3	tonnes	m		m^2		m^2		m		m^2
2.000	124.437	11.450	2736.48	2736.48	71.476	0.889	0.889	22.9	-1415.1	0.919	71.062	0.886	1880.5
2.050	124.610	11.450	2807.28	2807.28	71.465	0.890	0.890	23.5	-1417.1	0.921	71.038	0.886	1895.1
2.100	124.783	11.450	2878.19	2878.19	71.454	0.891	0.891	24.0	-1419.1	0.922	71.015	0.887	1909.7
2.150	124.962	11.450	2949.19	2949.19	71.443	0.891	0.891	24.6	-1421.1	0.923	70.991	0.888	1924.3
2.200	125.177	11.450	3020.31	3020.31	71.432	0.892	0.892	25.2	-1423.6	0.925	70.945	0.889	1939.3
2.250	125.392	11.450	3091.55	3091.55	71.421	0.893	0.893	25.7	-1426.2	0.927	70.898	0.889	1954.5
2.300	125.608	11.450	3162.92	3162.92	71.408	0.894	0.894	26.3	-1428.7	0.928	70.851	0.890	1969.6
2.350	125.805	11.450	3234.43	3234.43	71.395	0.894	0.894	26.9	-1431.2	0.930	70.804	0.891	1984.8
2.400	126.000	11.450	3306.05	3306.05	71.382	0.895	0.895	27.5	-1433.7	0.932	70.757	0.892	1999.9
2.450	126.196	11.450	3377.80	3377.80	71.368	0.896	0.896	28.0	-1436.2	0.933	70.708	0.892	2015.1
2.500	126.392	11.450	3449.66	3449.66	71.354	0.897	0.897	28.6	-1438.7	0.935	70.660	0.893	2030.3
2.550	126.588	11.450	3521.66	3521.66	71.339	0.897	0.897	29.2	-1441.1	0.936	70.611	0.894	2045.4
2.600	126.784	11.450	3593.77	3593.77	71.324	0.898	0.898	29.8	-1443.5	0.938	70.561	0.895	2060.6
2.650	126.980	11.450	3666.01	3666.01	71.309	0.899	0.899	30.3	-1445.9	0.940	70.511	0.895	2075.8
2.700	127.175	11.450	3738.36	3738.36	71.293	0.900	0.900	30.9	-1448.3	0.941	70.460	0.896	2091.1
2.750	127.371	11.450	3810.84	3810.84	71.276	0.900	0.900	31.5	-1450.7	0.943	70.409	0.897	2106.3
2.800	127.587	11.450	3883.43	3883.43	71.260	0.901	0.901	32.0	-1453.3	0.944	70.348	0.898	2121.7
2.850	127.900	11.450	3956.18	3956.18	71.242	0.902	0.902	32.6	-1456.8	0.947	70.245	0.898	2138.2
2.900	128.212	11.450	4029.11	4029.11	71.223	0.903	0.903	33.2	-1460.3	0.949	70.141	0.899	2154.6
2.950	128.524	11.450	4102.22	4102.22	71.203	0.904	0.904	33.8	-1463.9	0.951	70.038	0.900	2171.1
3.000	128.836	11.450	4175.49	4175.49	71.181	0.904	0.904	34.3	-1467.4	0.953	69.935	0.901	2187.6
3.050	129.149	11.450	4248.96	4248.96	71.159	0.905	0.905	34.9	-1470.9	0.956	69.832	0.902	2204.1
3.100	129.461	11.450	4322.58	4322.58	71.135	0.906	0.906	35.5	-1474.4	0.958	69.729	0.902	2220.6
3.150	129.773	11.450	4396.38	4396.38	71.111	0.907	0.907	36.1	-1477.9	0.960	69.626	0.903	2237.2
3.200	130.085	11.450	4470.37	4470.37	71.085	0.908	0.908	36.6	-1481.3	0.963	69.524	0.904	2253.8
3.250	130.397	11.450	4544.52	4544.52	71.059	0.909	0.909	37.2	-1484.8	0.965	69.421	0.905	2270.4
3.300	134.849	11.450	4619.03	4619.03	71.029	0.909	0.909	37.8	-1502.9	0.977	68.654	0.906	2302.0
3.350	134.889	11.450	4695.21	4695.21	70.976	0.911	0.911	38.3	-1531.7	0.995	67.458	0.907	2344.8
3.400	134.930	11.450	4771.80	4771.80	70.920	0.912	0.912	38.9	-1532.2	0.996	67.481	0.908	2359.4
3.450	134.970	11.450	4848.43	4848.43	70.866	0.913	0.913	39.5	-1532.8	0.996	67.504	0.910	2374.0
3.500	135.005	11.450	4925.07	4925.07	70.814	0.914	0.914	40.1	-1533.3	0.996	67.527	0.911	2388.7

Appendix 6.3 Overview developed resistance calculations

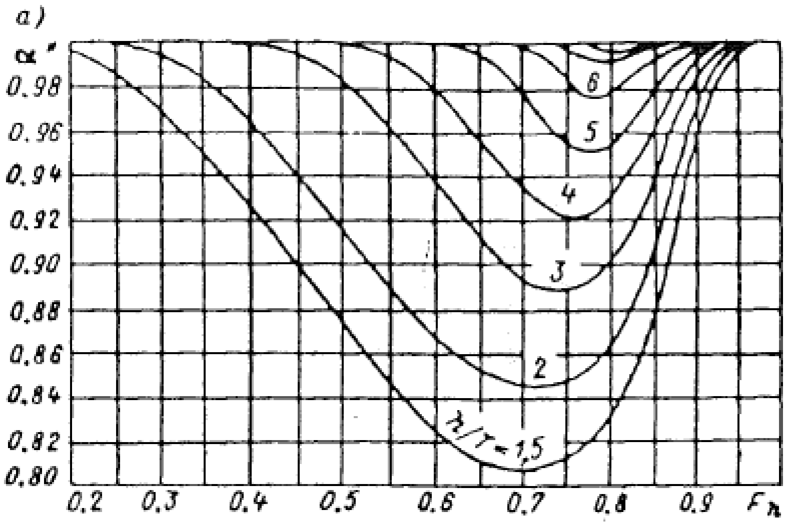
Referentie	Ref. No.	L/B-range	B/T-range	Fn-range	Syst.	R-presentatie	Turb. Stim.	Opmerkingen
Allan and Walker, 1948	1	5,6.2	3.7,4.0	.09–.24	Ja	C		Ondiep-water effect voor verschillende bakken
Blight en Dai, 1978	2	3.2–4.8	4.3–10	.03–.12	Nee	$R_T/(\Delta)$ en $C_T(S)$		4 Bakken met een grafische correctiemethode (niet betrouwbaar)
Dai et al., 1981	3	3–6	4–24	.06–.12	B/T	$C_T\Delta$ en $C_r(S)$	Trip wire	Enkele voor- en achterscheepsvormen
Hansa, 1957	4	3.0–5.3	3.3–11	.08–.25	Nee	$C_T(\Delta)$		10 Bakken
Hay, 1948	5	2.0–46.6	0.33–10	.00–.45	Ja	R_T/Δ		Groot aantal bakken met uit-eenlopende simpele vormen
Latorre en Ashcroft, 1981	6	1–6	2.5–12.5	.05–.21	Ja	$C_T(\Delta)$		Systematische voor- en achterscheepsvormvariatie
Muller en Binek, 1976	7	6.75	3–15.3	.00–.17		P_E [PS]		Systematische verbanden met Europa-bak IIa
Ohashi en Ikebuchi, 1977	8	1–4.8	3–5.62	.05–.25	Ja	$C_T(\Delta)$		Afrondingen in lateraal en horizontaal vlak
Todd, 1946	8	2.8–6.9	1.9–20.6	.06–.13	Nee	C		Bakken aan lange lijn gesleept
Zu-Qin, et al., 1981	10	3.5–5.5	4.5–10.0	.08–.19	Ja	$C_r(S)$	Trip wire	Systematische serie van sledevormige bakken

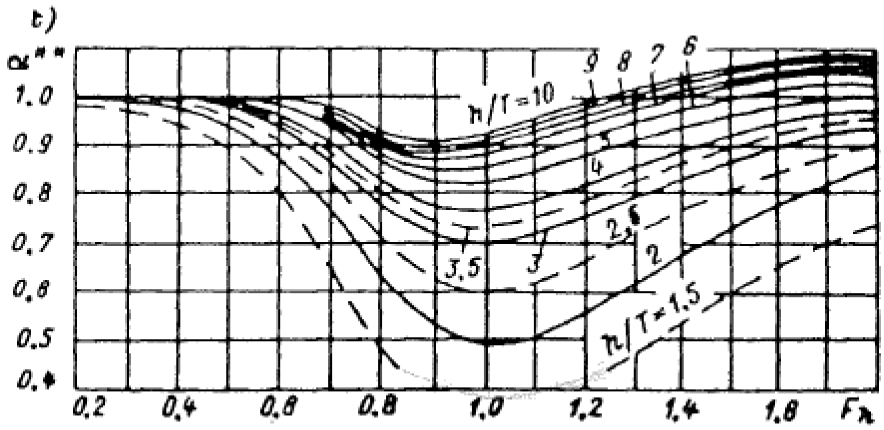
Appendix 6.4 Approximate $1+k_2$ values for R_{app}

Approximate $1 + k_2$ values	
rudder behind skeg	1.5 – 2.0
rudder behind stern	1.3 – 1.5
twin-screw balance rudders	2.8
shaft brackets	3.0
skeg	1.5 – 2.0
strut bossings	3.0
hull bossings	2.0
shafts	2.0 – 4.0
stabilizer fins	2.8
dome	2.7
bilge keels	1.4

source: (Holtrop, J, Mennen, GGJ, 1982)

Appendix 6.5 Shallow water resistance coefficients





Appendix 6.6 Input variables resistance methods

Van Terwisga Method

Van Terwisga Method					
L	135,00	*m*	P	0,00453	-
B	11,45	*m*	Cpst	0,15	-
T	2,90	*m*	Hva	0,51	*m*
V	6,00	*m/s*	Htr	0,20	*m*
Lentr	6,54	*m*	rst	4,00	*m*
rho	1000,00	*kg/m3*	ta	2,90	*m*
S	2060,00	*m2*	alfa-c	0,29	*rad*
Rn	711150131,69	-	Lst	8,00	*m*
Fnb	0,57	-	ca	0,0004	-
Cp	0,90	-	fnh	0,78	-
g	9,81	*m/s2*	h	6,00	*m*
visc	0,000001	*m2/s*	h/t	2,07	-
Atr	2,00	*m2*	Arudder	10,00	*m2*
alfa-st	0,37	*rad*	1+k2	2,80	-
Cd-tr	0,20	-	A*	0,86	*h/t=2*
Q	0,99	-	A**	0,67	*h/t=2*

Bolt Method

Bolt Method		
veff	6,084576	*m/s*
u	2,358151	*m/s*
am	32,87295	*m2*
ac	300	*m2*
fnh	0,782062	-
h	6	*m*
urel	8,358151	*m/s*
rf	198156	*N*
z	1,442294	*m*
rz	93962,9	*N*
rt	292118,9	*N*

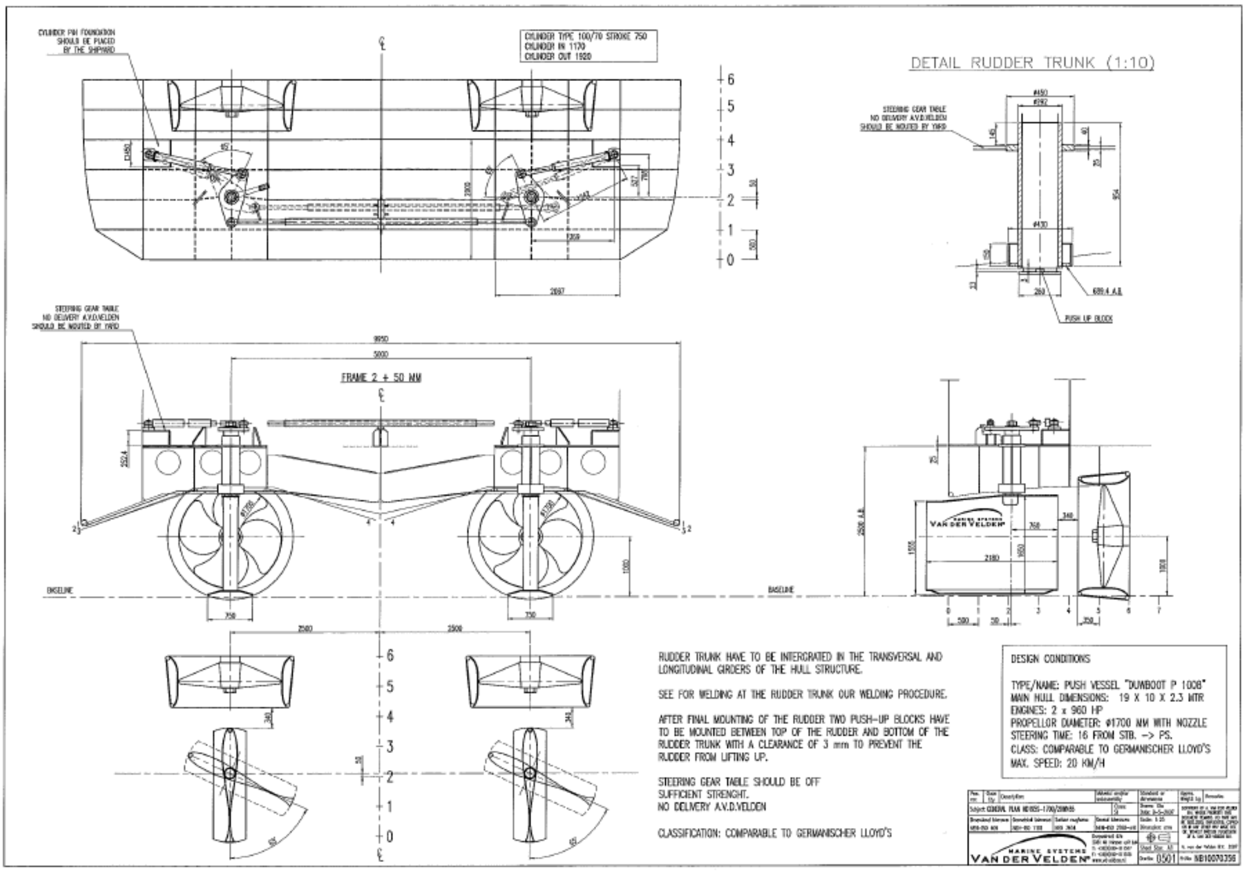
Holtrop & Menno Method

H&M Method		
Lpp	135	*m*
Lwl	135	*m*
B	11,45	*m*
T	2,9	*m*
Tf	2,9	*m*
Ta	2,9	*m*
Displ	4000	*m3*
Vm	4000	*m3*
Cb wl	0,892324	-
Cb pp	0,892324	-
Cm	0,99496	-
Cp wl	0,896845	-
Cwp	0,931137	-
Xb	4,312954	*m*
LCB	3,19478	*m*
Lr	22,89579	*m*
Ie	64,44687	*m*
Ab	0	*m2*
Hb	0	*m*
Cabt	0	-
Hb/Tf	0	-
At	2	*m2*
Cst	0	-
App(1+k)	80,50995	-
D thr	0	-
Cbto	0	-
S_2	2060	*m2*

Appendix 6.7 Overview database barges

Name	Length	tonnage	Pb (Kw)	Bowthruster (kW)	Source		Price
		3000	1343,28	0,00	debotshipbroker		
ms aspali		2200	1164,18	373,13	debotshipbroker		
stella maris		2402	970,15	0,00	debotshipbroker		
emulator		2104	701,49	186,57	debotshipbroker		
Alcyon		2350	970,15	320,90	debotshipbroker		
NN		2300	1194,03	0,00	debotshipbroker		
NN		3400	1119,40	0,00	debotshipbroker		
credo	85	1350	746,27	298,51	Kingma shiptrading		
Ganzepoo	135	3676	2388,06	671,64	Kingma shiptrading		
Paulina	105	2006	946,27	149,25	huizinga snijder		
	110	2801	1492,54	0,00	huizinga snijder		
		2987	1589,55	0,00	huizinga snijder		
		3864	1611,94	0,00	huizinga snijder		
Esperanto	190	4550	2270,15	416,42	kriesels scheepsmakelaar		
excelsior	135	4232	1402,99	261,19	kriesels scheepsmakelaar		
	110	3201	1343,28	485,07	kriesels scheepsmakelaar		
Rehoboth	135		1922,39	0,00	kriesels scheepsmakelaar		
aqua myra	110	3167	1513,43	335,82	kriesels scheepsmakelaar		
Pealko	110	3210	1268,66	485,07	kriesels scheepsmakelaar		
Cylor	135	3894	2058,21	820,90	kriesels scheepsmakelaar		
stil verk.	135		2462,69	0,00	kriesels scheepsmakelaar		
anja 1	99	2400	1082,09	261,19	kriesels scheepsmakelaar		
stil verk.	135	3901	1940,30	970,15	kriesels scheepsmakelaar		
stilverk	135	4846	2270,15	0,00	kriesels scheepsmakelaar		
Marshal m	110	2924	1940,30	395,52	kriesels scheepsmakelaar		
Marinier	110	3107	1643,28	283,58	kriesels scheepsmakelaar		
Camaro V	135	3255	1074,63	537,31	kriesels scheepsmakelaar		
Casa Nova	110	3250	1399,25	559,70	kriesels scheepsmakelaar		
fenny 1	110	3250	1028,36	335,82	kriesels scheepsmakelaar		
nieuwbou	135	5540	1922,39	746,27	kriesels scheepsmakelaar		
nieuwbou	135	4230	1922,39	777,61	kriesels scheepsmakelaar		
Elan	105	2304	746,27	208,96	Piu Allegro		
	95	2850	1089,55	373,13	Piu Allegro		
	110	2530	1194,03	421,64	Piu Allegro		3200000
	110	2507	1492,54	223,88	Piu Allegro		1650000
Ambro	110	4163	1276,12	313,43	GTS schepen.nl		2.350.000
Renjo	108	3600	1880,60	447,76	GTS schepen.nl		1.925.000
siam	110	3177	1044,78	208,96	GTS schepen.nl		2.450.000
helena jac	110	2991	0,00	470,15	GTS schepen.nl		4.125.000
Marco Pol	135	3888	2059,70	671,64	Galle makelaars		5.650.000
Mondeo	110	3207	1267,91	453,73	Galle makelaars		4.200.000
Noordenv	110	3257	1324,63	597,01	Galle makelaars		3.900.000
Cura dei	110	3100	1339,55	395,52	Galle makelaars		3.800.000
Justin	110	3300	1192,54	335,82	Galle makelaars		3.000.000
FIXUT MAI	135	3502	1791,04	701,49	Galle makelaars		
groenend	135	3696	1589,55	798,51	Galle makelaars		
Descanso	135	3950	1589,55	798,51	Maasland scheepsvaart		5.950.000
Marjo r	110	3214	1291,04	395,52	Maasland scheepsvaart		

Appendix 6.8 Tunnel Design aft ship



Appendix 6.9 Specifications Diesel Engine Albert Canal Barge

CATERPILLAR® 3406 C — 242 bkW / 325 bhp, 1800 rpm

Industrial

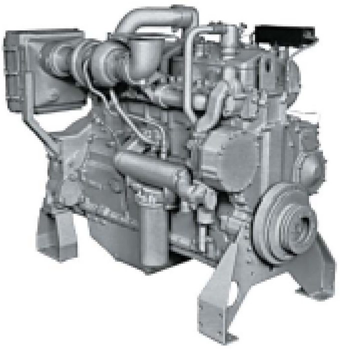


Image shown may not reflect actual engine

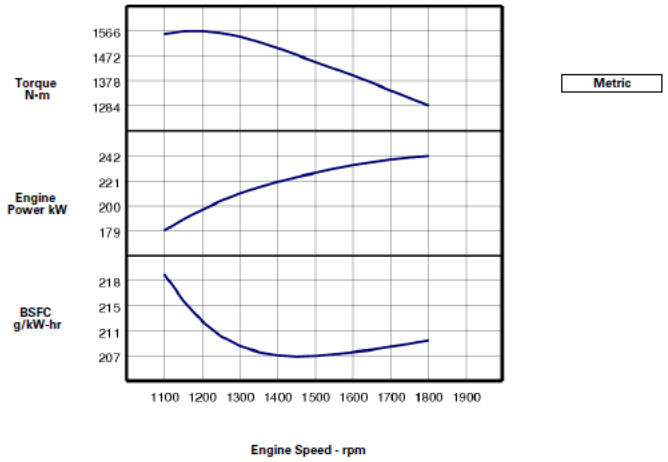
CATERPILLAR ENGINE SPECIFICATIONS

I-6, 4-Stroke-Cycle Diesel

Bore.......137.2 mm (5.4 in)
Stroke.......165.1 mm (6.5 in)
Displacement....... 14.64 L (893.39 in³)
Aspiration.......Turbocharged / Aftercooled
Compression Ratio.......15.9:1
Rotation (from flywheel end)....... Counterclockwise
Capacity for Liquids
Cooling System....... 20.8 L (5.5 gal)
Lube Oil System (refill)....... 38.0 L (10.0 gal)
Engine Weight, Net Dry (approximate)..1,343 kg (2,961 lb)

PERFORMANCE CURVES

IND - A (Continuous) - DM2175-01



Engine Speed rpm	Engine Power kW	Torque N•m	BSFC g/kW-hr	Fuel Rate L/hr
1800	242	1284	209.5	60.4
1750	241	1313	209	59.9
1700	239	1342	208.6	59.3
1650	237	1370	208.2	58.7
1600	234	1398	207.9	58.0
1550	231	1424	207.6	57.2
1500	228	1449	207.4	56.3
1450	224	1475	207.3	55.3
1400	220	1501	207.5	54.3
1350	215	1524	207.9	53.2
1300	210	1544	208.7	52.0
1250	204	1558	210.1	50.8
1200	197	1566	212.1	49.5
1150	188	1565	214.9	48.1
1100	179	1554	218.5	46.6

Appendix 6.10 Specifications Genset Albert Canal Barge

Caterpillar 3406 C Gen source: www.cat.com

TECHNICAL DATA

Open Generator Set - - 1800 rpm/60 Hz/480 Volts	DM2267	
Low Fuel Consumption		
Generator Set Package Performance		
Genset Power rating @ 0.8 pf	375 kVA	
Genset Power rating with fan	300 ekW	
Fuel Consumption		
100% load with fan	86.6 L/hr	22.9 Gal/hr
75% load with fan	66.3 L/hr	17.5 Gal/hr
50% load with fan	47.8 L/hr	12.6 Gal/hr
Cooling System[1]		
Air flow restriction (system)	0.12 kPa	0.48 in. water
Air flow (max @ rated speed for radiator arrangement)	684 m³/min	24155 cfm
Engine Coolant capacity with radiator/exp. tank	57.8 L	15.3 gal
Engine coolant capacity	20.8 L	5.5 gal
Radiator coolant capacity	37.0 L	9.8 gal
Inlet Air		
Combustion air inlet flow rate	24.4 m³/min	861.7 cfm
Exhaust System		
Exhaust stack gas temperature	538.8 ° C	1001.8 ° F
Exhaust gas flow rate	69.4 m³/min	2450.8 cfm
Heat rejection to aftercooler	28 kW	1592 Btu/min
Exhaust flange size (internal diameter)	152.4 mm	6.0 in
Exhaust system backpressure (maximum allowable)	6.7 kPa	26.9 in. water
Heat rejection		
Heat rejection to coolant (total)	200 kW	11374 Btu/min
Heat rejection to exhaust (total)	322 kW	18312 Btu/min
Heat rejection to atmosphere from engine	67 kW	3810 Btu/min
Heat rejection to atmosphere from generator	21.9 kW	1245.5 Btu/min
Alternator[2]		
Motor starting capability @ 30% voltage dip	682 skVA	
Frame	LC5014J	
Temperature Rise	150 ° C	270 ° F
Lube System		
Sump refill with filter	38.0 L	10.0 gal
Emissions[3]		
NOx g/hp-hr	7.76 g/hp-hr	
CO g/hp-hr	1.51 g/hp-hr	
HC g/hp-hr	.09 g/hp-hr	
PM g/hp-hr	.425 g/hp-hr	

Package Dimensions		
Length	4264.3 mm	167.89 in
Width	1110.0 mm	43.7 in
Height	2150.0 mm	84.65 in
Weight	3120 kg	6,878 lb

Appendix 6.11 Specifications Emergency generator

DIESEL GENERATOR SET **CATERPILLAR®**

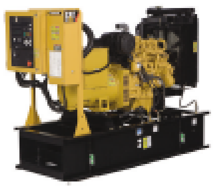


Image shown may not reflect actual package.

STANDBY
30 ekW 37 kVA
60 Hz 1800 rpm 208 Volts

Caterpillar is leading the power generation marketplace with Power Solutions engineered to deliver unmatched flexibility, expandability, reliability, and cost-effectiveness.

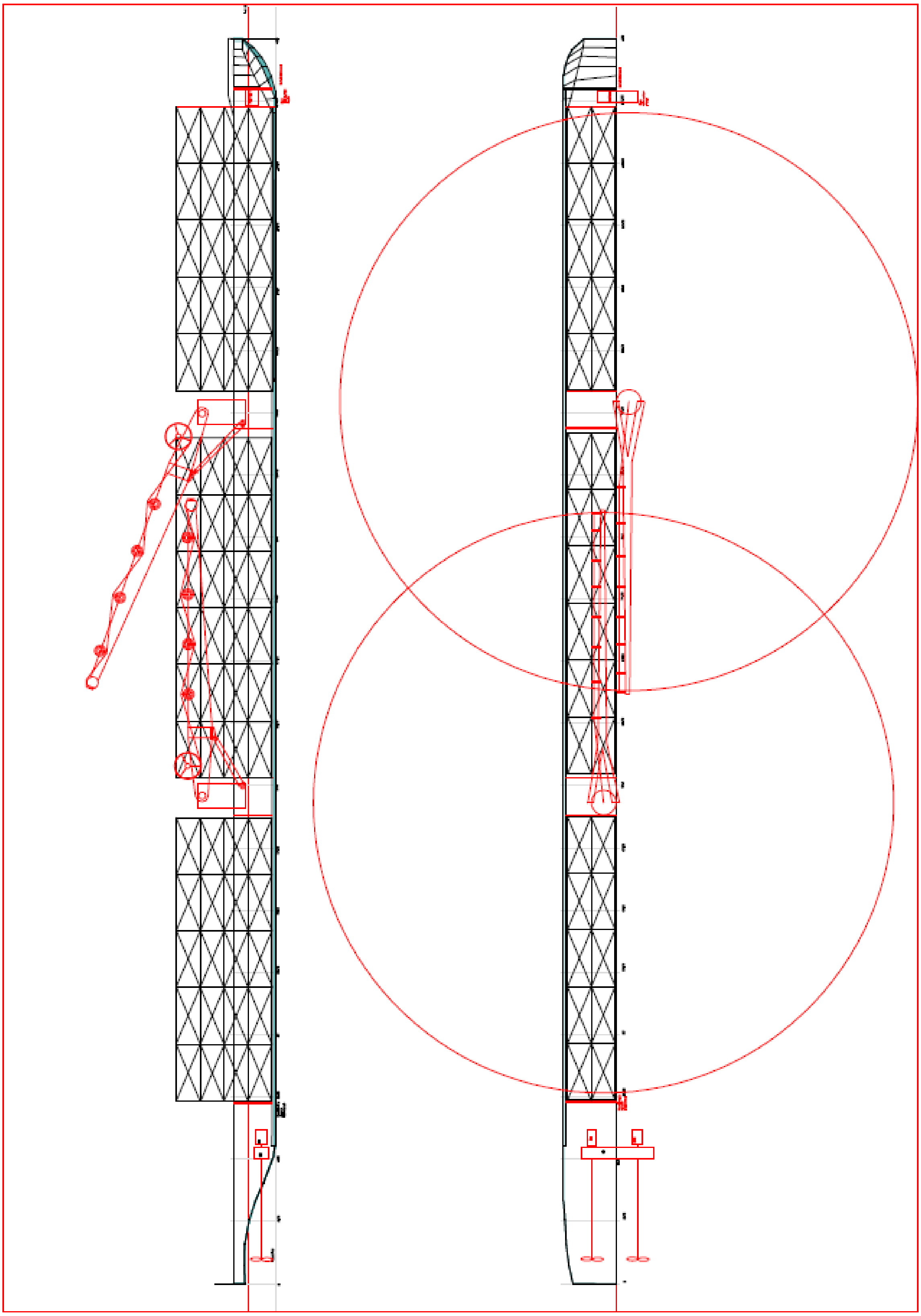
TECHNICAL DATA

Open Generator Set - - 1800 rpm/60 Hz/208 Volts	P3524A	
EPA Tier 4 Interim		
Generator Set Package Performance		
Genset Power rating @ 0.8 pf	37.5 kVA	
Genset Power rating with fan	30 ekW	
Fuel Consumption		
100% load with fan	10.7 L/hr	2.8 Gal/hr
Cooling System [1]		
Air flow restriction (system)	0.12 kPa	0.48 in. water
Air flow (max @ rated speed for radiator arrangement)	75 m^3/min	2649 cfm
Engine coolant capacity	3.6 L	1.0 gal
Exhaust System		
Exhaust gas flow rate	2.5 m^3/min	88.3 cfm
Exhaust flange size (internal diameter)	6.4 mm	0.3 in
Heat Rejection		
Heat rejection to exhaust (total)	33 kW	1877 Btu/min
Heat rejection to atmosphere from generator	3.7 kW	210.4 Btu/min
Alternator [2]		
Motor starting capability @ 30% voltage dip	55 skVA	
Frame	LC1014S	
Temperature Rise	150 ° C	270 ° F
Emissions (Nominal)		
NOx g/hp-hr	5.43 g/hp-hr	
CO g/hp-hr	.78 g/hp-hr	
HC g/hp-hr	.09 g/hp-hr	
PM g/hp-hr	.323 g/hp-hr	

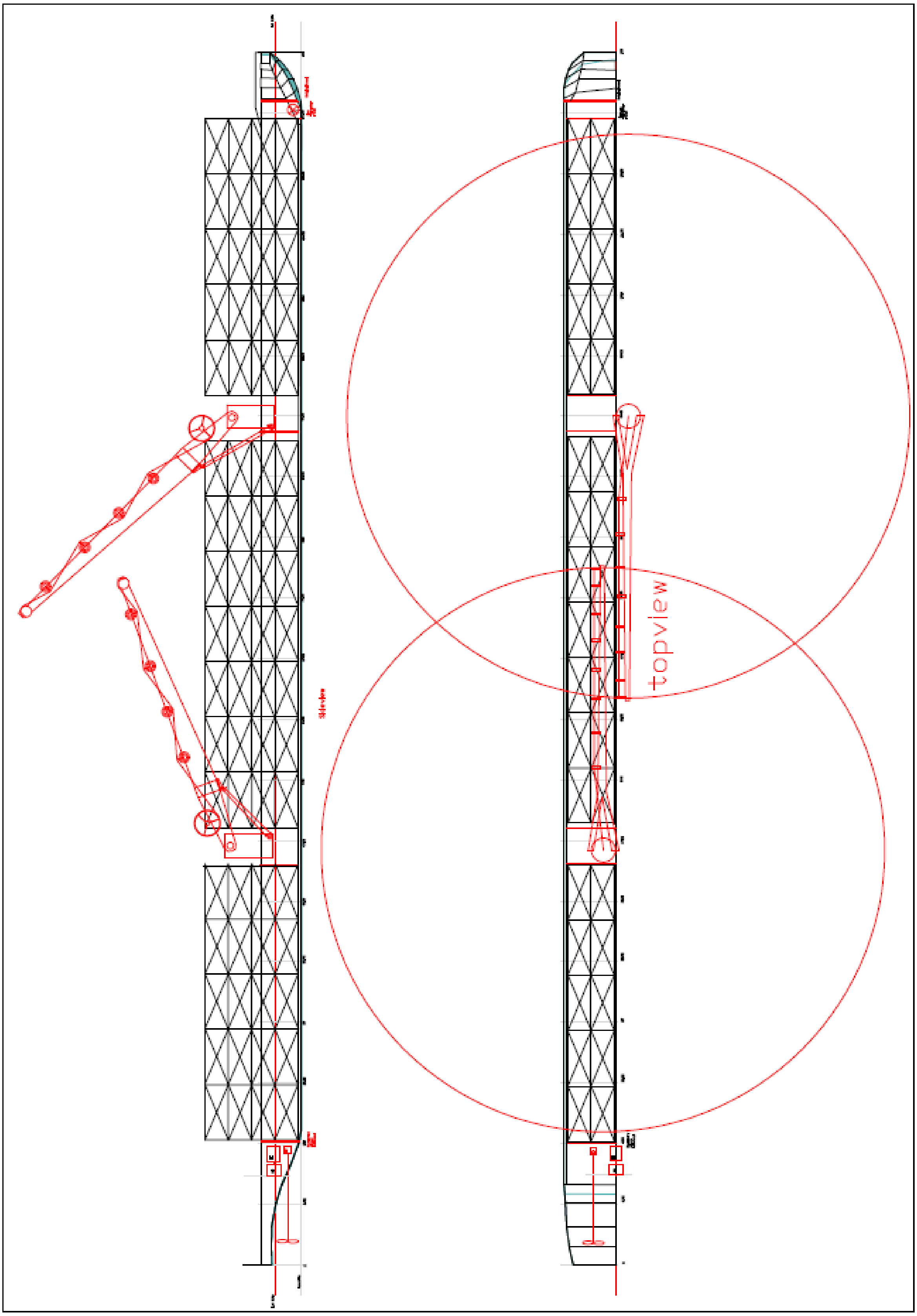
[1] For ambient and altitude capabilities consult your Caterpillar dealer. Airflow restriction (system) is added to existing restriction from factory.
[2] Generator temperature rise is based on a 40 C (104 F) ambient per NEMA MG1-32.

Package Dimensions		
Length	710.0 mm	27.95 in
Width	489.0 mm	19.25 in
Height	726.0 mm	28.58 in
Weight	487 kg	1,074 lb

Appendix 6.12 General Arrangement Diesel Direct Albert canal barge



Appendix 6.13 General Arrangement Diesel electric Albert canal barge



Appendix 6.14 Specification Diesel Engine hybrid barge

CATERPILLAR® **C32 ACERT™**

MARINE PROPULSION

1319 mhp (1300 bhp) 970 bkW

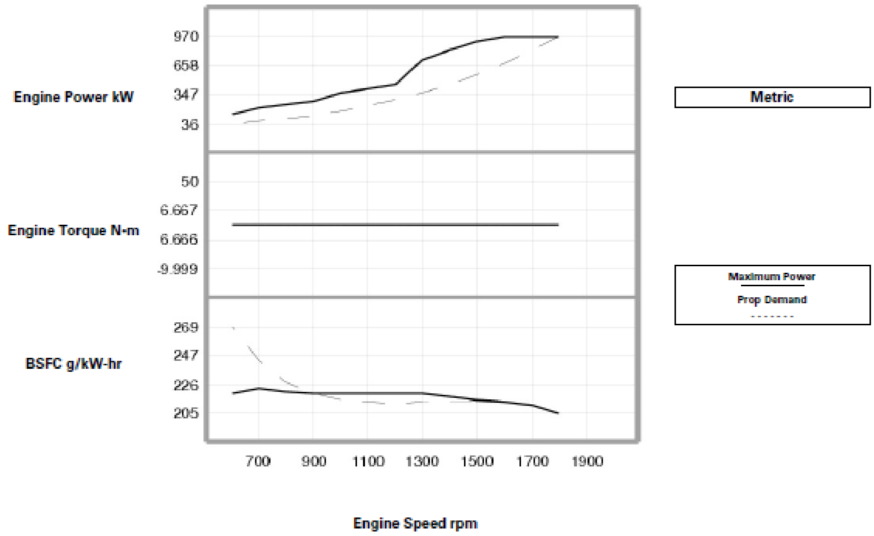
Image shown may not reflect actual Engine

SPECIFICATIONS

V-12, 4-Stroke-Cycle-Diesel

Displacement.................................. 32.1 L (1958.8 cu. in.)
Rated Engine Speed.. 1800
Bore.. 145.0 mm (5.71 in)
Stroke.. 162.0 mm (6.38 in)
Aspiration... TTA
Governor... Electronic
Cooling System... Heat Exchanger
Weight, Net Dry (approx)...................... 2,840 kg (6,261 lb)
Refill Capacity
Cooling System...80 L (21.1 gal)
Lube Oil System................................... 138 L (36.5 gal)
Oil Change Interval... 500 hr
Caterpillar Diesel Engine Oil 10W30 or 15W40
Rotation (from flywheel end).. CCW
Flywheel and Flywheel Housing.........................SAE No. 0
Flywheel Teeth

C-RATING - DM9604-02



Maximum Power Data					Prop Demand Data				
Engine Speed rpm	Engine Power kW	Engine Torque N·m	BSFC g/kW-hr	Fuel Rate L/hr	Engine Speed rpm	Engine Power kW	Engine Torque N·m	BSFC g/kW-hr	Fuel Rate L/hr
1800	970	5143	204.6	236.5	1800	969.5	5143	204.6	236.5
1700	970	5446	210.1	242.8	1700	816.7	4588	210.2	204.6
1600	970	5786	212.5	245.6	1600	680.9	4064	212.4	172.4
1500	911	5800	214.4	232.8	1500	561.1	3572	212.8	142.3
1400	826	5634	216.5	213.2	1400	456.2	3111	212.8	115.7
1300	717	5267	218.7	186.9	1300	365.2	2683	212.3	92.4
1200	460	3661	219	120.1	1200	287.3	2286	212	72.6
1000	369	3524	218.3	96.0	1000	166.2	1587	213.8	42.4
900	278	2950	219	72.6	900	121.2	1286	218.5	31.6
800	246	2936	221.5	64.9	800	85.1	1016	228.3	23.2
700	204	2783	223.1	54.3	700	57	778	244.8	16.6
600	139	2212	220.1	36.5	600	35.9	571	268.7	11.5

NOTE: Prop demand data is a cubic prop demand curve with 3.0 exponent for displacement hulls only.

Engine Dimensions		
(1) Length to Flywheel Housing	2072.6 mm	81.6 in
(2) Width	1447.4 mm	56.98 in
(3) Height	1539.6 mm	60.61 in
Weight, Net Dry (approx)	2840 kg	6,261 lb

Appendix 6.15 Weight list stability calculations

Lightship						
Description	Weight	VCG	LCG	TCG	Aft	Forward
	(tonnes)	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*
crane 1	25.00	8.000	52.000	0.000 (CL)	50.000	54.000
jib 1	31.00	10.000	52.000	0.000 (CL)	50.000	54.000
crane 2	25.00	8.000	94.000	0.000 (CL)	92.000	96.000
jib 2	31.00	10.000	94.000	0.000 (CL)	92.000	96.000
supplies	45.00	0.500	30.000	0.000 (CL)	0.000	50.000
anchor	22.00	4.000	130.000	0.000 (CL)	130.000	131.000
piping	22.00	1.000	50.000	0.000 (CL)	0.000	135.000
machinery	67.00	1.500	12.000	0.000 (CL)	0.000	30.000
deckhouse	39.00	5.000	10.000	0.000 (CL)	0.000	20.000
hull	567.00	1.500	67.500	0.000 (CL)	0.000	0.000

Miscellaneous						
Description	Weight	VCG	LCG	TCG	Aft	Forward
	(tonnes)	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*
Contra weight	100.00	1.500	67.500	4.500 (PS)	60.000	70.000
2 containers high	60.00	20.000	67.500	-10.000 (SB)	40.000	80.000
2 containers far	60.00	5.000	40.000	-25.000 (SB)	39.000	41.000
container layer 4	750.00	8.750	75.000	0.000 (CL)	20.000	130.000
container layer 3	960.00	6.300	75.000	0.000 (CL)	20.000	130.000
container layer 2	960.00	3.850	75.000	0.000 (CL)	20.000	130.000
container layer 1	960.00	1.400	75.000	0.000 (CL)	20.000	130.000

Appendix 6.16 Results stability calculations Delftship

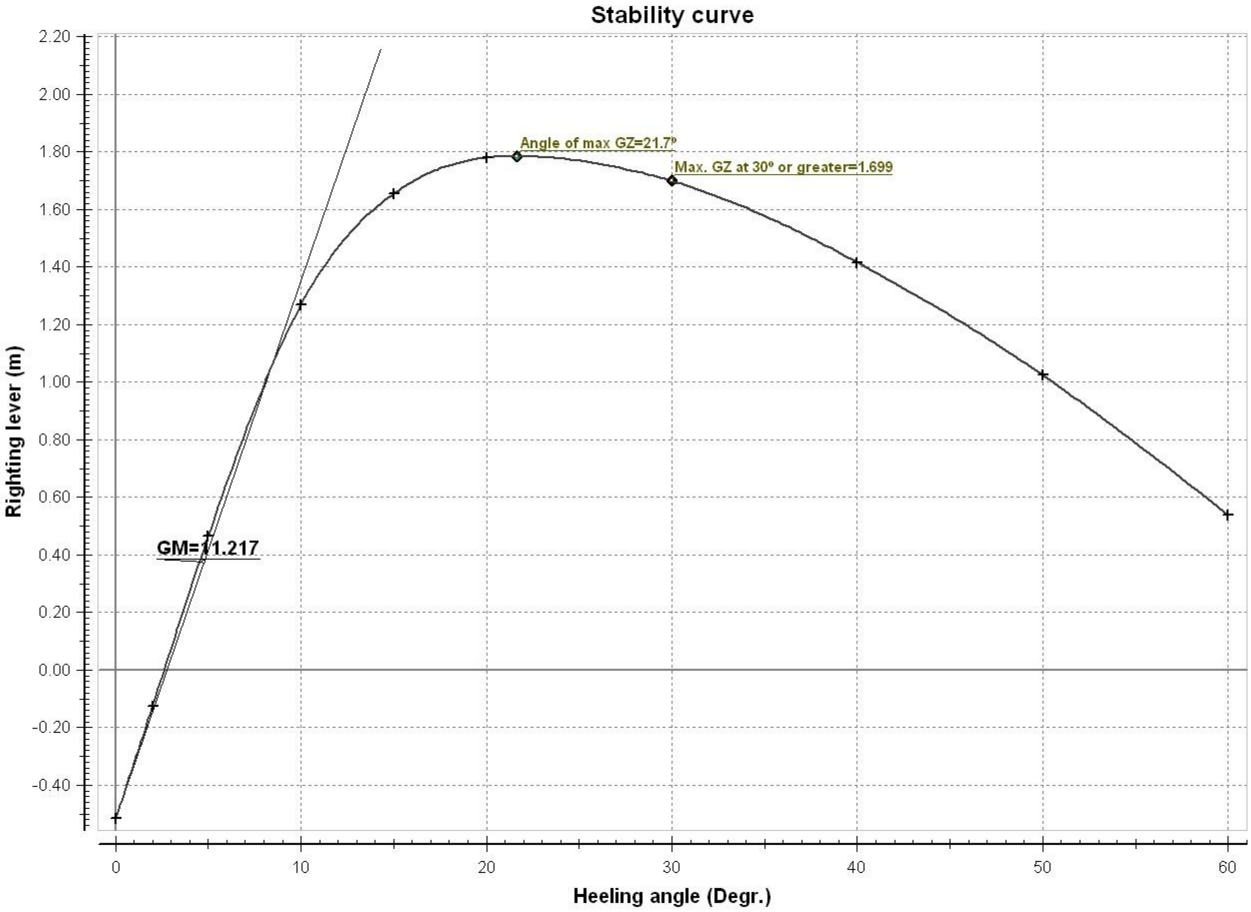
Loadcase: empty unloading high

Hydrostatic particulars

List	-2.63 (SB)	*(Degr.)*		**KM**	14.746	*(m)*
Draft aft	1.236	*(m)*		**GM solid**	11.217	*(m)*
Moulded draft	0.798	*(m)*		**GG'**	0.000	*(m)*
Draft forward	0.359	*(m)*		**GM liquid**	11.217	*(m)*
Trim	-0.877	*(m)*		**Volume**	1034.1	*(m^3)*
				Relative water density	1.0000	
				LCF	70.675	*(m)*
				Immersion rate	13.639	*(t/cm)*
				MCT	119.26	*(t*m/cm)*

GZ values

Heeling angle	Draft	Trim	KN sin(ø)	VCG sin(ø)	GN sin(ø)	GZ
(Degr.)	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*
0.00 (CL)	0.798	-0.877	0.000	-0.516	0.516	-0.516
-2.00 (SB)	0.798	-0.877	0.515	-0.639	0.139	-0.124
-5.00 (SB)	0.796	-0.878	1.287	-0.822	-0.428	0.465
-10.00 (SB)	0.762	-0.998	2.391	-1.121	-1.198	1.269
-15.00 (SB)	0.643	-1.192	3.067	-1.412	-1.560	1.655
-20.00 (SB)	0.448	-1.353	3.472	-1.692	-1.681	1.780
-30.00 (SB)	-0.131	-1.617	3.910	-2.212	-1.662	1.699
-40.00 (SB)	-0.996	-1.841	4.080	-2.664	-1.538	1.416
-50.00 (SB)	-2.287	-2.165	4.059	-3.035	-1.403	1.024
-60.00 (SB)	-4.346	-2.889	3.853	-3.314	-1.280	0.539

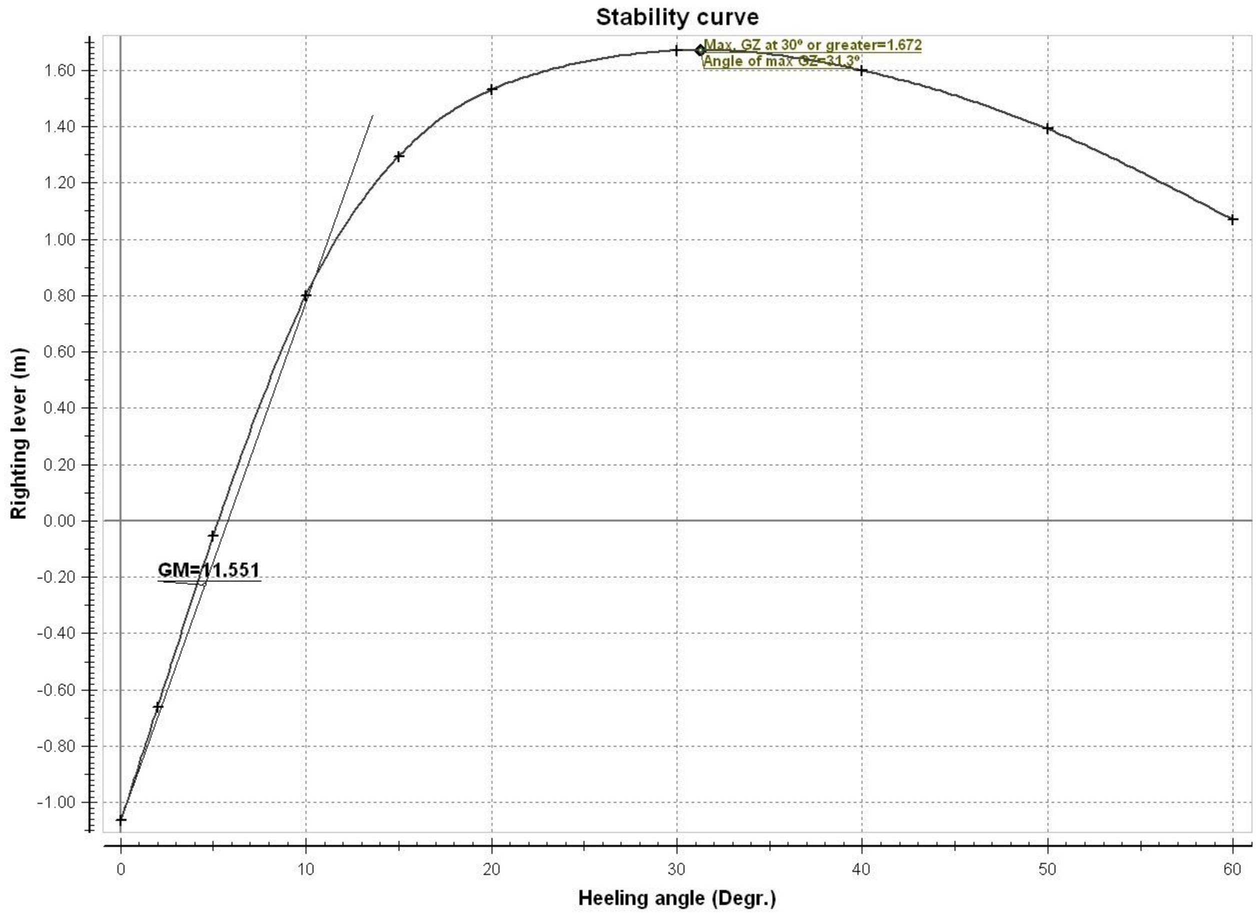

Stability curve
Angle of max GZ=21.7º
Max. GZ at 30º or greater=1.699
GM=11.217
Righting lever (m)
Heeling angle (Degr.)
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
0
10
20
30
40
50
60

Loadcase: empty unloading far

Hydrostatic particulars						
List	-5.27 (SB)	*(Degr.)*		**KM**	14.128	*(m)*
Draft aft	1.357	*(m)*		**GM solid**	11.552	*(m)*
Moulded draft	0.836	*(m)*		**GG'**	0.001	*(m)*
Draft forward	0.316	*(m)*		**GM liquid**	11.551	*(m)*
Trim	-1.041	*(m)*		**Volume**	1084.9	*(m^3)*
				Relative water density	1.0000	
				LCF	69.800	*(m)*
				Immersion rate	13.508	*(t/cm)*
				MCT	116.47	*(t*m/cm)*

GZ values

Heeling angle	Draft	Trim	KN sin(ø)	VCG sin(ø)	GN sin(ø)	GZ
(Degr.)	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*
0.00 (CL)	0.839	-1.033	0.000	-1.065	1.065	-1.065
-2.00 (SB)	0.839	-1.033	0.493	-1.154	0.677	-0.661
-5.00 (SB)	0.837	-1.036	1.232	-1.285	0.093	-0.053
-10.00 (SB)	0.803	-1.166	2.296	-1.496	-0.723	0.800
-15.00 (SB)	0.692	-1.397	2.991	-1.696	-1.190	1.295
-20.00 (SB)	0.504	-1.596	3.414	-1.883	-1.417	1.531
-30.00 (SB)	-0.063	-1.924	3.882	-2.213	-1.605	1.670
-40.00 (SB)	-0.913	-2.223	4.075	-2.476	-1.678	1.599
-50.00 (SB)	-2.174	-2.722	4.056	-2.665	-1.717	1.391
-60.00 (SB)	-4.177	-3.753	3.845	-2.776	-1.749	1.069


Stability curve
Max. GZ at 30º or greater=1.672
Angle of max GZ=31.3º
GM=11.551
Righting lever (m)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
0
10
20
30
40
50
60
Heeling angle (Degr.)

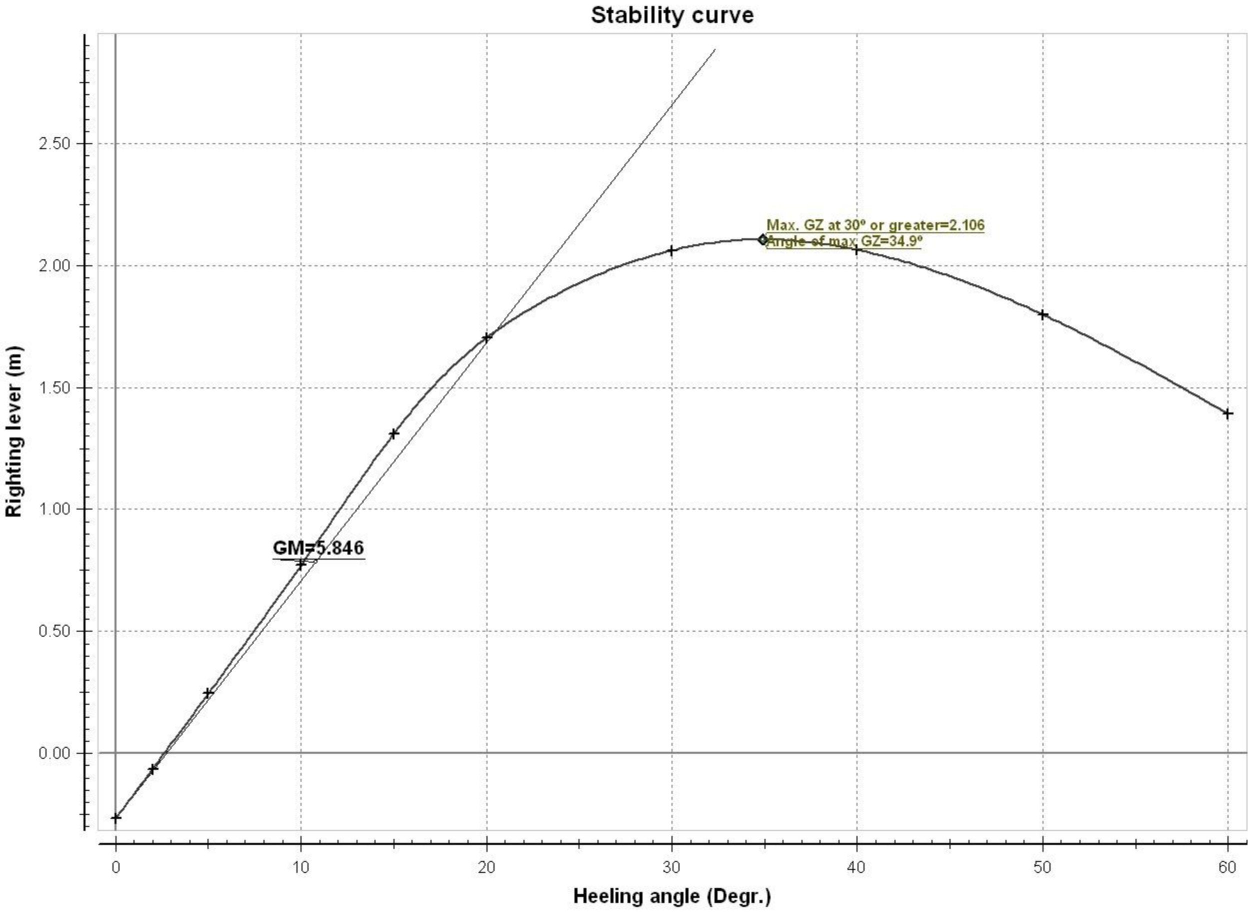
Loadcase: 1 container layer unloading high

Hydrostatic particulars

List	-2.62 (SB)	*(Degr.)*		**KM**	8.350	*(m)*
Draft aft	1.759	*(m)*		**GM solid**	5.846	*(m)*
Moulded draft	1.485	*(m)*		**GG'**	0.000	*(m)*
Draft forward	1.211	*(m)*		**GM liquid**	5.846	*(m)*
Trim	-0.548	*(m)*		**Volume**	1993.9	*(m^3)*
				Relative water density	1.0000	
				LCF	70.816	*(m)*
				Immersion rate	13.966	*(t/cm)*
				MCT	128.03	*(t*m/cm)*

GZ values

Heeling angle	**Draft**	**Trim**	**KN sin(ø)**	**VCG sin(ø)**	**GN sin(ø)**	**GZ**
(Degr.)	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*
0.00 (CL)	1.486	-0.549	0.000	-0.268	0.268	-0.268
-2.00 (SB)	1.485	-0.549	0.292	-0.355	0.090	-0.063
-5.00 (SB)	1.484	-0.547	0.730	-0.485	-0.180	0.245
-10.00 (SB)	1.480	-0.541	1.470	-0.699	-0.641	0.772
-15.00 (SB)	1.469	-0.543	2.216	-0.907	-1.114	1.309
-20.00 (SB)	1.404	-0.589	2.811	-1.108	-1.451	1.703
-30.00 (SB)	1.062	-0.633	3.546	-1.484	-1.747	2.062
-40.00 (SB)	0.503	-0.773	3.878	-1.815	-1.782	2.063
-50.00 (SB)	-0.259	-1.000	3.889	-2.090	-1.677	1.799
-60.00 (SB)	-1.428	-1.354	3.695	-2.302	-1.554	1.393


Stability curve
Max. GZ at 30º or greater=2.106
Angle of max GZ=34.9º
GM=5.846
Righting lever (m)
Heeling angle (Degr.)
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60

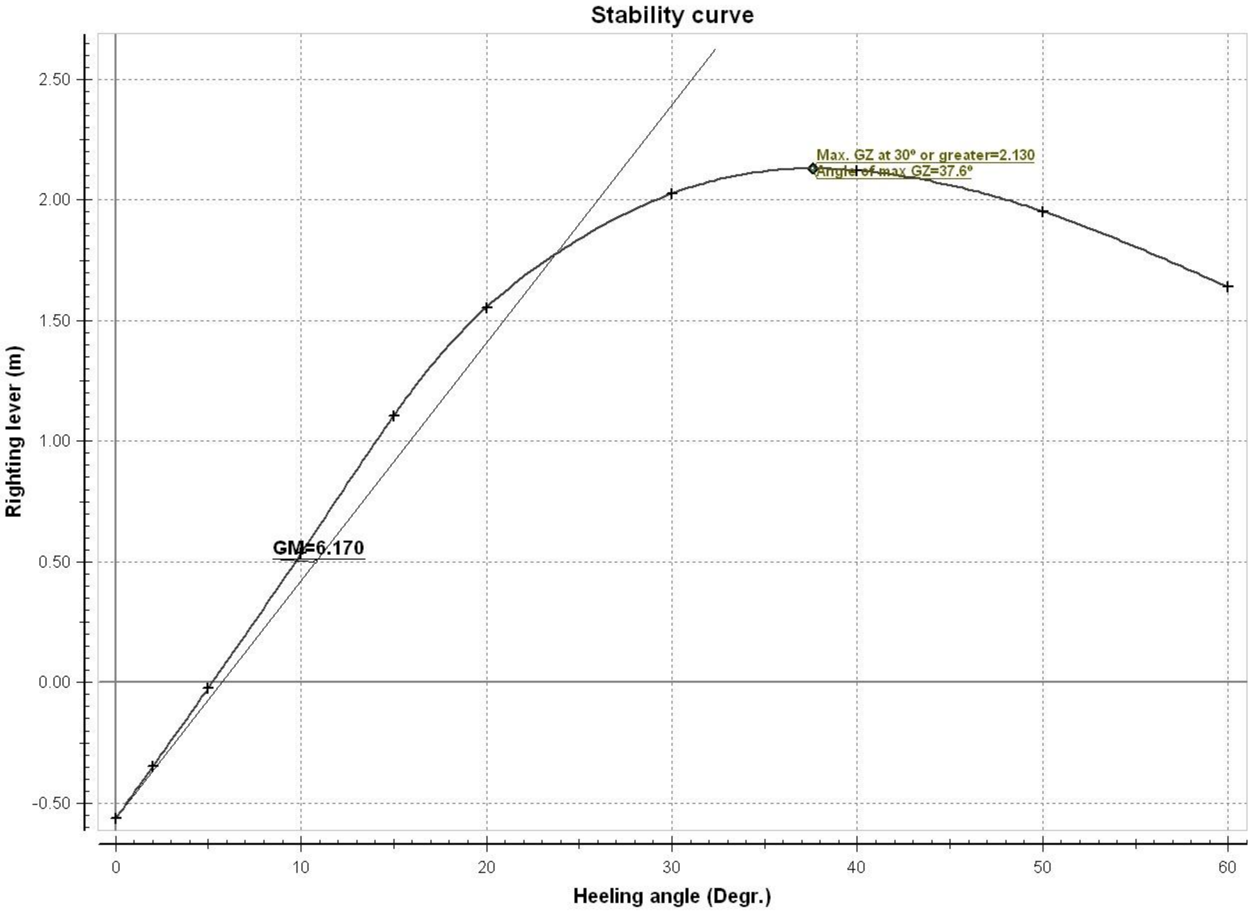
Loadcase: 1 container layer unloading far

Hydrostatic particulars

List	-5.20 (SB)	*(Degr.)*		**KM**	8.194	*(m)*
Draft aft	1.865	*(m)*		**GM solid**	6.171	*(m)*
Moulded draft	1.524	*(m)*		**GG'**	0.001	*(m)*
Draft forward	1.182	*(m)*		**GM liquid**	6.170	*(m)*
Trim	-0.683	*(m)*		**Volume**	2044.3	*(m^3)*
				Relative water density	1.0000	
				LCF	70.675	*(m)*
				Immersion rate	14.030	*(t/cm)*
				MCT	129.04	*(t*m/cm)*

GZ values

Heeling angle	Draft	Trim	KN sin(ø)	VCG sin(ø)	GN sin(ø)	GZ
(Degr.)	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*
0.00 (CL)	1.525	-0.685	0.000	-0.565	0.565	-0.565
-2.00 (SB)	1.525	-0.685	0.286	-0.635	0.376	-0.349
-5.00 (SB)	1.524	-0.683	0.717	-0.739	0.090	-0.022
-10.00 (SB)	1.520	-0.676	1.443	-0.908	-0.401	0.535
-15.00 (SB)	1.509	-0.678	2.176	-1.070	-0.905	1.106
-20.00 (SB)	1.449	-0.737	2.778	-1.223	-1.294	1.555
-30.00 (SB)	1.118	-0.818	3.528	-1.501	-1.697	2.027
-40.00 (SB)	0.584	-1.052	3.856	-1.734	-1.821	2.122
-50.00 (SB)	-0.144	-1.426	3.868	-1.915	-1.806	1.953
-60.00 (SB)	-1.259	-2.044	3.678	-2.038	-1.768	1.639


Stability curve
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
Righting lever (m)
0
10
20
30
40
50
60
Heeling angle (Degr.)
GM=6.170
Max. GZ at 30º or greater=2.130
Angle of max GZ=37.6º

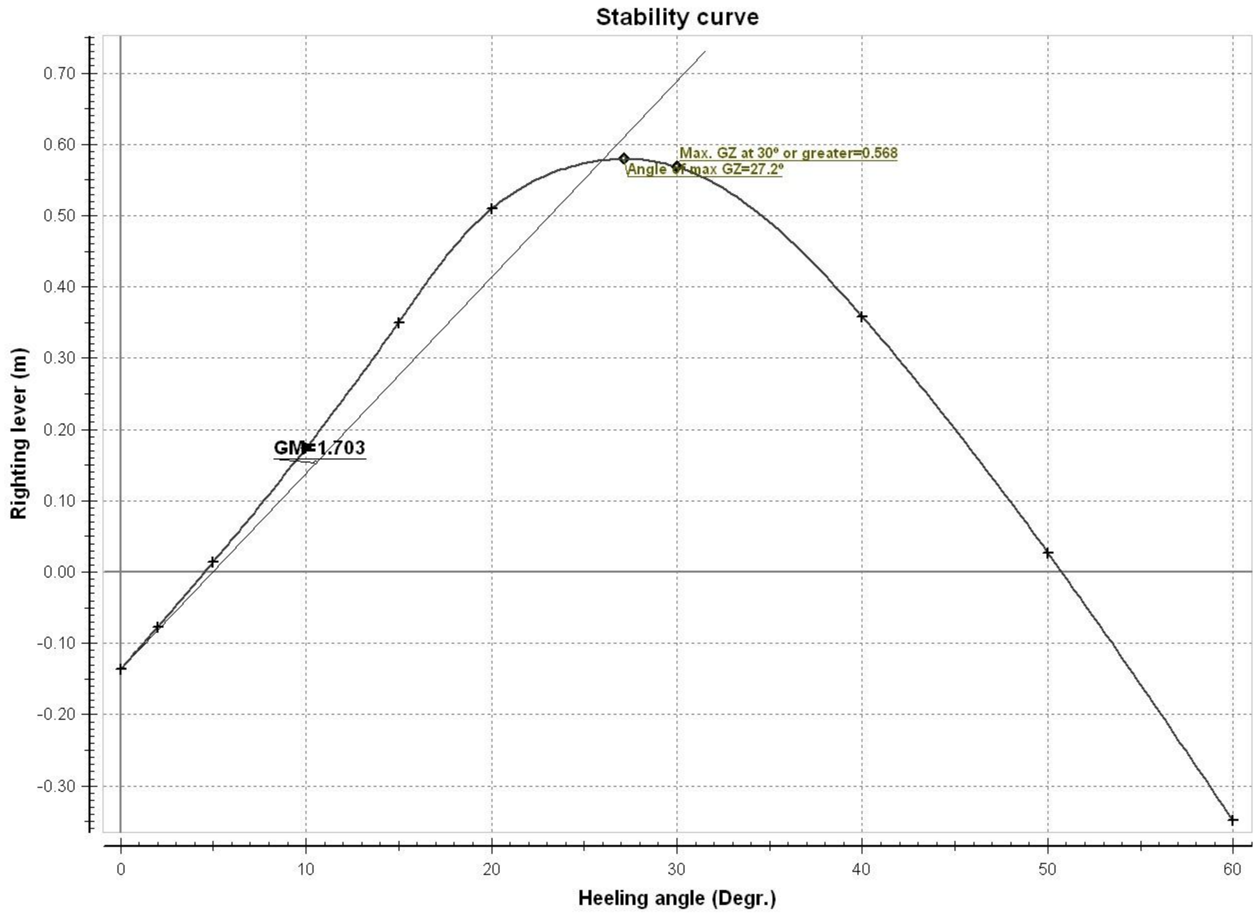
Loadcase: 3 container layers unloading high

Hydrostatic particulars

List	-4.53 (SB)	*(Degr.)*		**KM**	5.468	*(m)*
Draft aft	2.785	*(m)*		**GM solid**	1.703	*(m)*
Moulded draft	2.818	*(m)*		**GG'**	0.000	*(m)*
Draft forward	2.851	*(m)*		**GM liquid**	1.703	*(m)*
Trim	0.065	*(m)*		**Volume**	3913.8	*(m^3)*
				Relative water density	1.0000	
				LCF	70.287	*(m)*
				Immersion rate	14.600	*(t/cm)*
				MCT	145.71	*(t*m/cm)*

GZ values

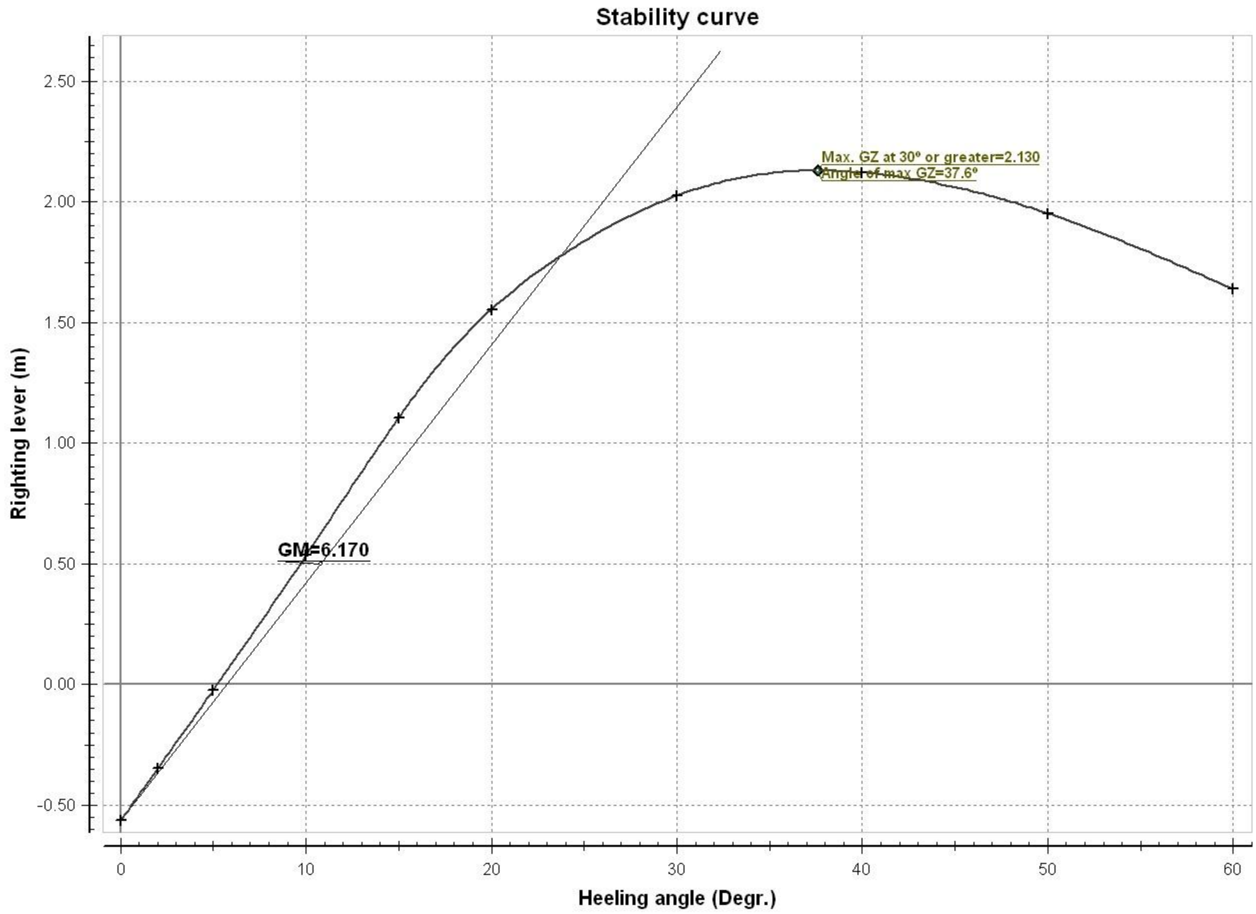
Heeling angle	Draft	Trim	KN sin(ø)	VCG sin(ø)	GN sin(ø)	GZ
(Degr.)	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*
0.00 (CL)	2.820	0.061	0.000	-0.136	0.136	-0.136
-2.00 (SB)	2.819	0.062	0.191	-0.268	0.127	-0.077
-5.00 (SB)	2.818	0.067	0.478	-0.464	0.111	0.014
-10.00 (SB)	2.812	0.090	0.963	-0.788	0.075	0.174
-15.00 (SB)	2.802	0.127	1.457	-1.106	0.022	0.350
-20.00 (SB)	2.808	0.189	1.926	-1.416	-0.018	0.510
-30.00 (SB)	3.006	0.358	2.569	-2.001	0.126	0.568
-40.00 (SB)	3.316	0.614	2.883	-2.525	0.458	0.358
-50.00 (SB)	3.734	0.961	2.999	-2.972	0.818	0.027
-60.00 (SB)	4.375	1.494	2.980	-3.329	1.129	-0.349


Stability curve
Max. GZ at 30° or greater=0.568
Angle of max GZ=27.2°
GM=1.703
Righting lever (m)
Heeling angle (Degr.)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
0
10
20
30
40
50
60

Loadcase: 3 container layers unloading far

Hydrostatic particulars						
List	-5.20 (SB)	*(Degr.)*		KM	8.194	*(m)*
Draft aft	1.865	*(m)*		GM solid	6.171	*(m)*
Moulded draft	1.524	*(m)*		GG'	0.001	*(m)*
Draft forward	1.182	*(m)*		GM liquid	6.170	*(m)*
Trim	-0.683	*(m)*		Volume	2044.3	*(m^3)*
				Relative water density	1.0000	
				LCF	70.675	*(m)*
				Immersion rate	14.030	*(t/cm)*
				MCT	129.04	*(t*m/cm)*

GZ values						
Heeling angle	Draft	Trim	KN sin(ø)	VCG sin(ø)	GN sin(ø)	GZ
(Degr.)	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*
0.00 (CL)	1.525	-0.685	0.000	-0.565	0.565	-0.565
-2.00 (SB)	1.525	-0.685	0.286	-0.635	0.376	-0.349
-5.00 (SB)	1.524	-0.683	0.717	-0.739	0.090	-0.022
-10.00 (SB)	1.520	-0.676	1.443	-0.908	-0.401	0.535
-15.00 (SB)	1.509	-0.678	2.176	-1.070	-0.905	1.106
-20.00 (SB)	1.449	-0.737	2.778	-1.223	-1.294	1.555
-30.00 (SB)	1.118	-0.818	3.528	-1.501	-1.697	2.027
-40.00 (SB)	0.584	-1.052	3.856	-1.734	-1.821	2.122
-50.00 (SB)	-0.144	-1.426	3.868	-1.915	-1.806	1.953
-60.00 (SB)	-1.259	-2.044	3.678	-2.038	-1.768	1.639


Stability curve
Max. GZ at 30º or greater=2.130
Angle of max GZ=37.6º
GM=6.170
Righting lever (m)
Heeling angle (Degr.)
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
0
10
20
30
40
50
60

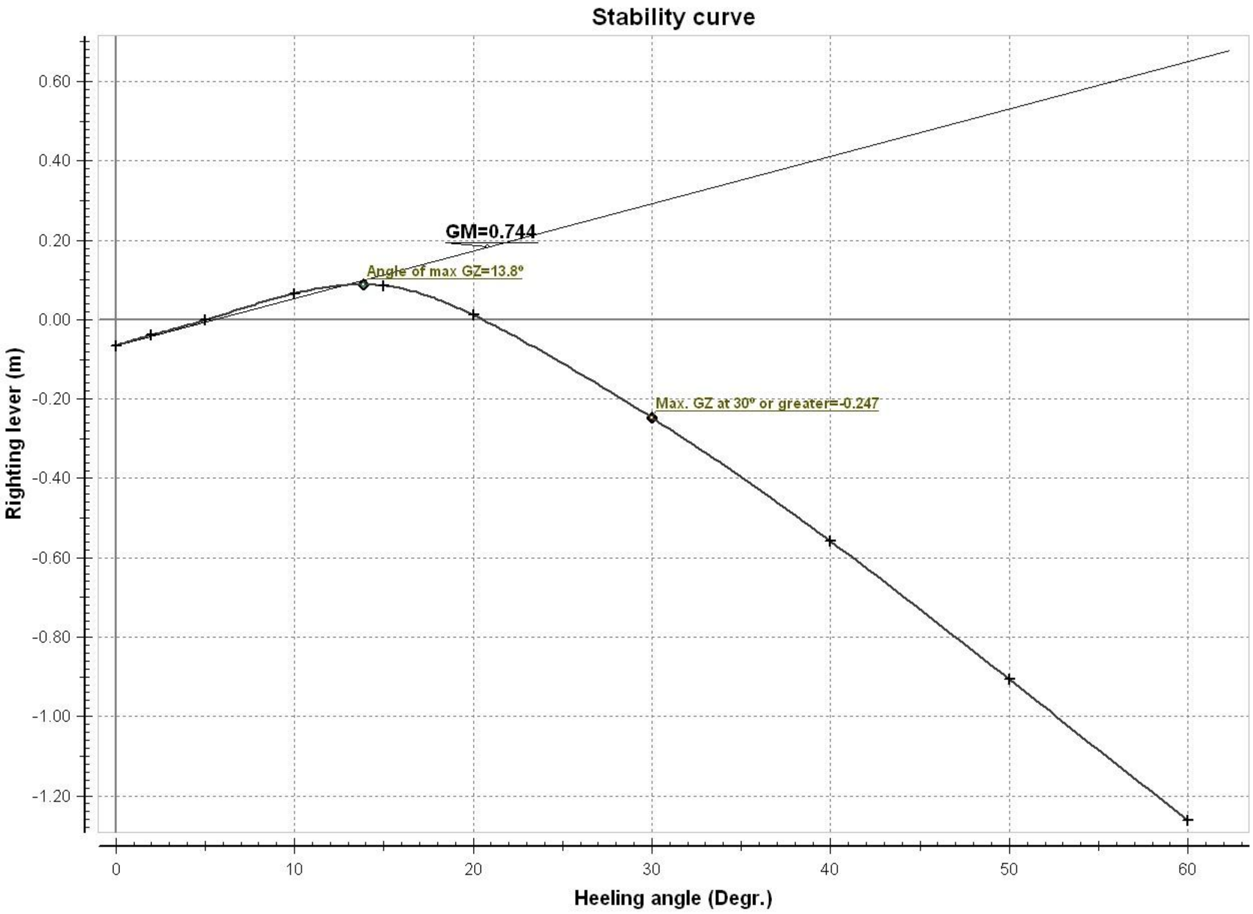
Loadcase: fully loaded unloading high

Hydrostatic particulars

List	-5.06 (SB)	*(Degr.)*		**KM**	5.189	*(m)*
Draft aft	3.448	*(m)*		**GM solid**	0.745	*(m)*
Moulded draft	3.416	*(m)*		**GG'**	0.000	*(m)*
Draft forward	3.383	*(m)*		**GM liquid**	0.744	*(m)*
Trim	-0.065	*(m)*		**Volume**	4798.6	*(m^3)*
				Relative water density	1.0000	
				LCF	68.218	*(m)*
				Immersion rate	15.190	*(t/cm)*
				MCT	164.17	*(t*m/cm)*

GZ values

Heeling angle	Draft	Trim	KN sin(ø)	VCG sin(ø)	GN sin(ø)	GZ
(Degr.)	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*
0.00 (CL)	3.418	-0.075	0.000	-0.065	0.065	-0.065
-2.00 (SB)	3.418	-0.074	0.181	-0.220	0.100	-0.039
-5.00 (SB)	3.416	-0.066	0.451	-0.452	0.153	-0.001
-10.00 (SB)	3.411	-0.040	0.902	-0.836	0.237	0.066
-15.00 (SB)	3.439	-0.010	1.299	-1.213	0.365	0.086
-20.00 (SB)	3.549	0.023	1.593	-1.581	0.578	0.012
-30.00 (SB)	3.959	0.103	2.031	-2.279	1.082	-0.247
-40.00 (SB)	4.635	0.209	2.349	-2.907	1.584	-0.558
-50.00 (SB)	5.607	0.395	2.541	-3.447	2.053	-0.907
-60.00 (SB)	7.095	0.705	2.620	-3.882	2.452	-1.263


Stability curve
GM=0.744
Angle of max GZ=13.8°
Max. GZ at 30° or greater=-0.247
Righting lever (m)
Heeling angle (Degr.)
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
-1.20
0
10
20
30
40
50
60

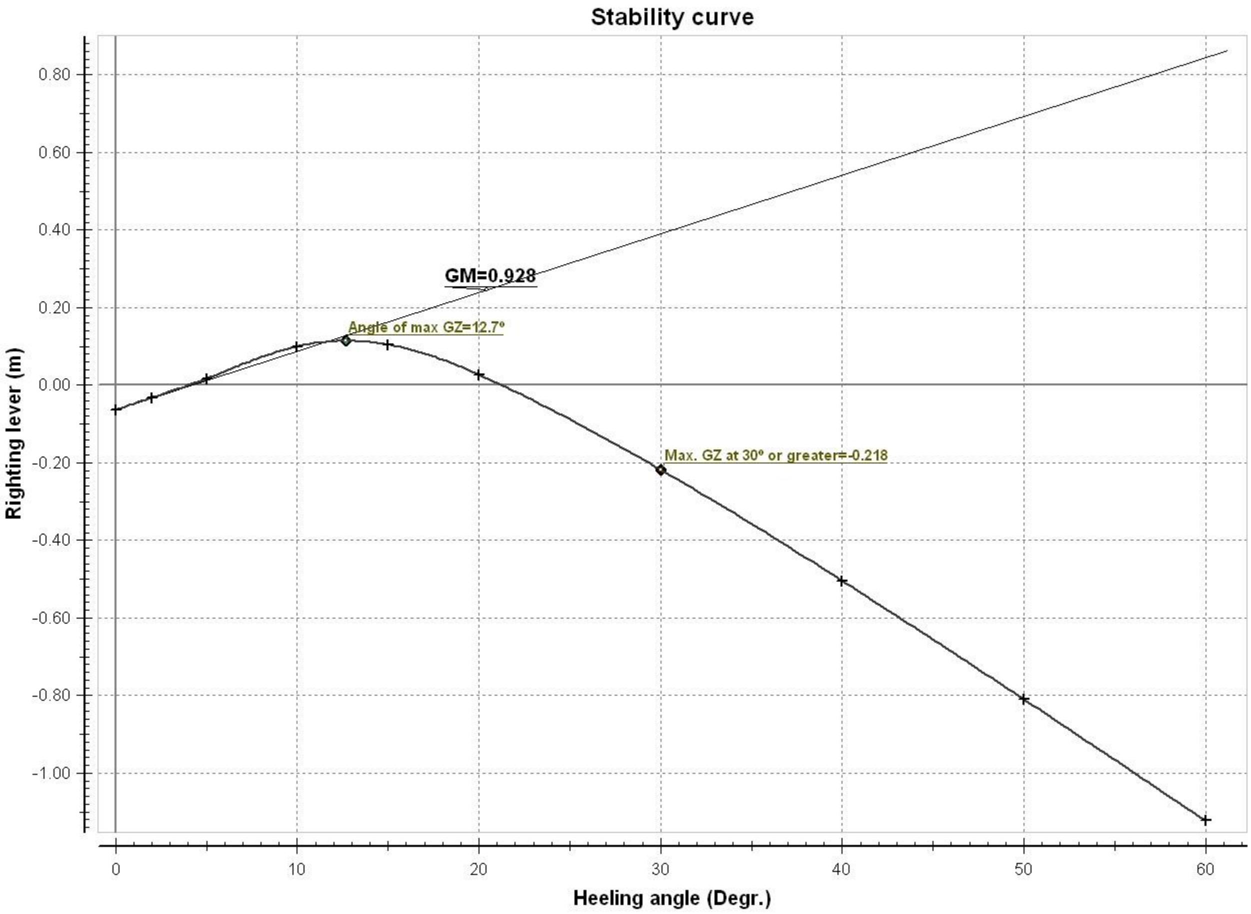
Loadcase: fully loaded unloading far

Hydrostatic particulars

List	-3.95 (SB)	*(Degr.)*		**KM**	5.135	*(m)*
Draft aft	3.578	*(m)*		**GM solid**	0.928	*(m)*
Moulded draft	3.524	*(m)*		**GG'**	0.000	*(m)*
Draft forward	3.470	*(m)*		**GM liquid**	0.928	*(m)*
Trim	-0.108	*(m)*		**Volume**	4962.2	*(m^3)*
				Relative water density	1.0000	
				LCF	67.706	*(m)*
				Immersion rate	15.304	*(t/cm)*
				MCT	168.26	*(t*m/cm)*

GZ values

Heeling angle	Draft	Trim	KN sin(ø)	VCG sin(ø)	GN sin(ø)	GZ
(Degr.)	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*
0.00 (CL)	3.524	-0.108	0.000	-0.064	0.064	-0.064
-2.00 (SB)	3.524	-0.108	0.179	-0.211	0.095	-0.032
-5.00 (SB)	3.523	-0.105	0.448	-0.431	0.140	0.017
-10.00 (SB)	3.519	-0.087	0.894	-0.794	0.213	0.100
-15.00 (SB)	3.572	-0.076	1.255	-1.151	0.360	0.104
-20.00 (SB)	3.705	-0.059	1.527	-1.499	0.580	0.028
-30.00 (SB)	4.158	-0.014	1.941	-2.159	1.079	-0.218
-40.00 (SB)	4.882	0.047	2.249	-2.753	1.568	-0.504
-50.00 (SB)	5.957	0.145	2.454	-3.264	2.012	-0.810
-60.00 (SB)	7.601	0.303	2.552	-3.675	2.386	-1.123


Stability curve
GM=0.928
Angle of max GZ=12.7°
Max. GZ at 30° or greater=-0.218
Righting lever (m)
Heeling angle (Degr.)
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
0
10
20
30
40
50
60

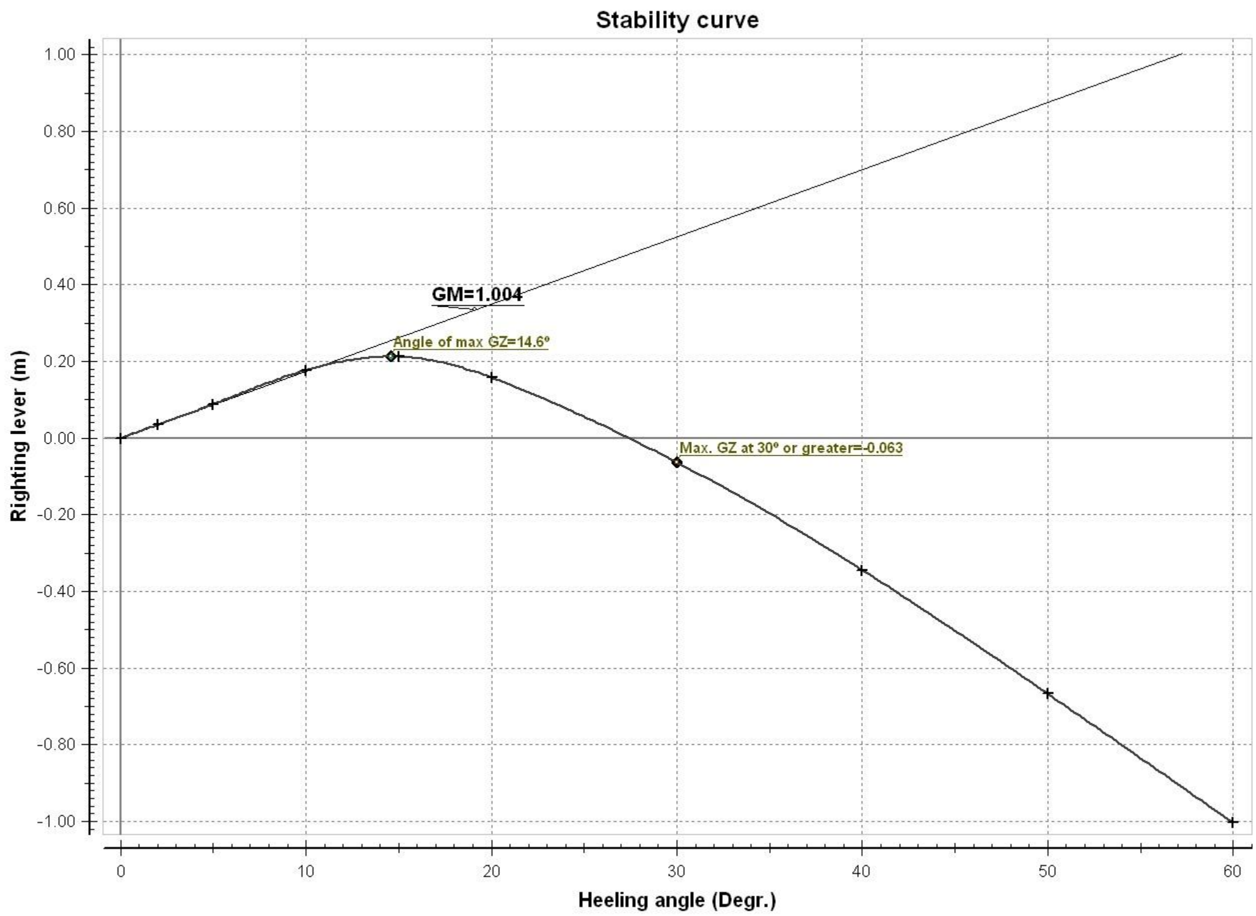
Loadcase: fully loaded equipment centered

Hydrostatic particulars

List	0.00 (CL)	*(Degr.)*		**KM**	5.185	*(m)*
Draft aft	3.687	*(m)*		**GM solid**	1.004	*(m)*
Moulded draft	3.423	*(m)*		**GG'**	0.000	*(m)*
Draft forward	3.159	*(m)*		**GM liquid**	1.004	*(m)*
Trim	-0.528	*(m)*		**Volume**	4807.7	*(m^3)*
				Relative water density	1.0000	
				LCF	67.367	*(m)*
				Immersion rate	15.297	*(t/cm)*
				MCT	168.71	*(t*m/cm)*

GZ values

Heeling angle	**Draft**	**Trim**	**KN sin(ø)**	**VCG sin(ø)**	**GN sin(ø)**	**GZ**
(Degr.)	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*
0.00 (CL)	3.423	-0.528	0.000	0.000	0.000	0.000
2.00 (PS)	3.423	-0.528	0.181	0.146	-0.026	0.035
5.00 (PS)	3.422	-0.529	0.453	0.364	-0.064	0.088
10.00 (PS)	3.420	-0.520	0.904	0.726	-0.126	0.178
15.00 (PS)	3.457	-0.592	1.294	1.082	-0.240	0.212
20.00 (PS)	3.571	-0.671	1.588	1.430	-0.434	0.158
30.00 (PS)	3.990	-0.811	2.027	2.090	-0.901	-0.063
40.00 (PS)	4.671	-0.973	2.343	2.687	-1.374	-0.344
50.00 (PS)	5.660	-1.292	2.536	3.203	-1.820	-0.667
60.00 (PS)	7.170	-1.784	2.617	3.621	-2.200	-1.004


Stability curve
GM=1.004
Angle of max GZ=14.6º
Max. GZ at 30º or greater=-0.063
Righting lever (m)
Heeling angle (Degr.)
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
0
10
20
30
40
50
60

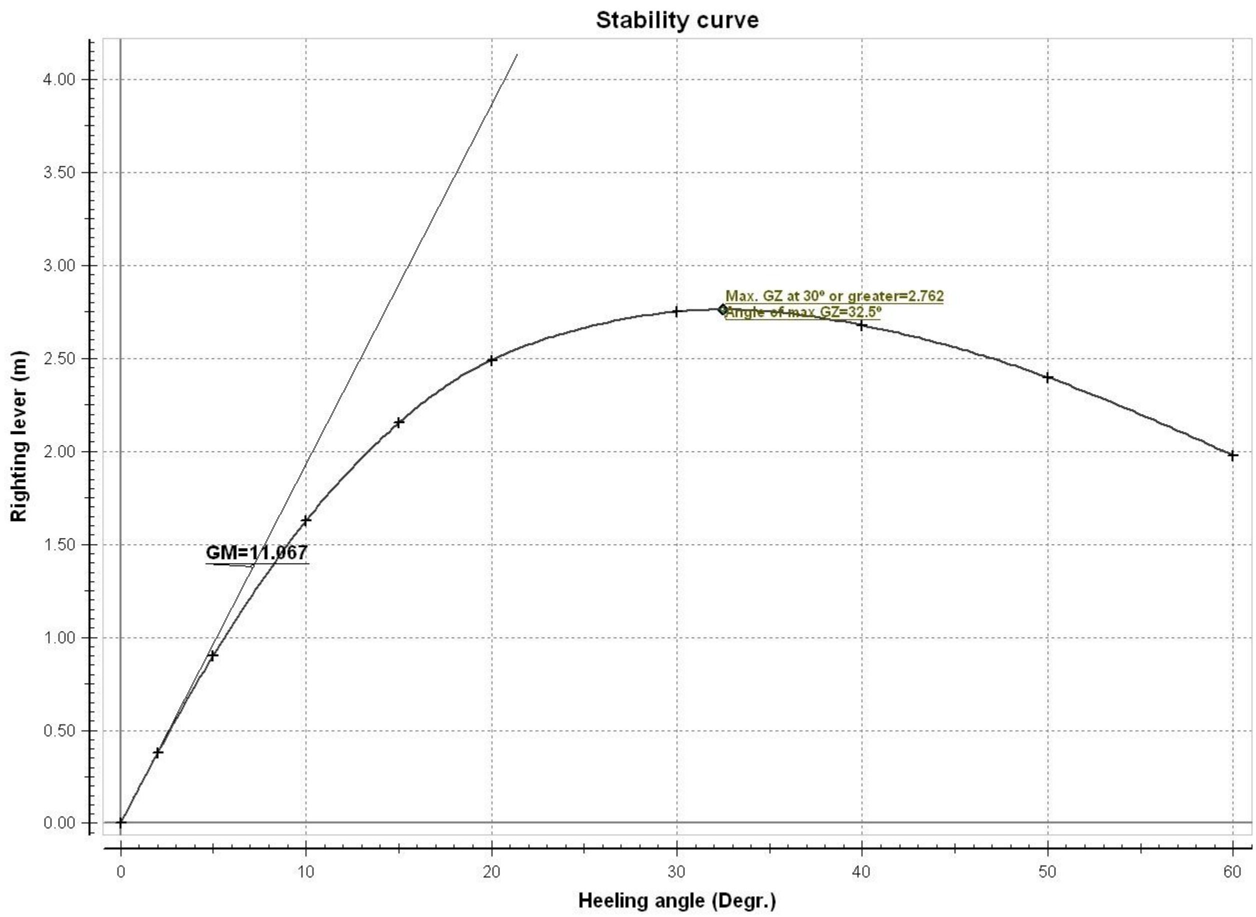
Loadcase: empty equipment centered

Hydrostatic particulars

List	0.00 (CL)	*(Degr.)*	**KM**	13.146	*(m)*
Draft aft	1.953	*(m)*	**GM solid**	11.067	*(m)*
Moulded draft	0.925	*(m)*	**GG'**	0.000	*(m)*
Draft forward	-0.103	*(m)*	**GM liquid**	11.067	*(m)*
Trim	-2.056	*(m)*	**Volume**	1177.7	*(m^3)*
			Relative water density	1.0000	
			LCF	68.892	*(m)*
			Immersion rate	13.556	*(t/cm)*
			MCT	117.33	*(t*m/cm)*

GZ values

Heeling angle	**Draft**	**Trim**	**KN sin(ø)**	**VCG sin(ø)**	**GN sin(ø)**	**GZ**
(Degr.)	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*
0.00 (CL)	0.925	-2.056	0.000	0.000	0.000	0.000
2.00 (PS)	0.923	-2.071	0.451	0.073	0.357	0.378
5.00 (PS)	0.909	-2.144	1.083	0.181	0.849	0.902
10.00 (PS)	0.849	-2.402	1.988	0.361	1.524	1.627
15.00 (PS)	0.729	-2.763	2.691	0.538	2.006	2.153
20.00 (PS)	0.544	-3.118	3.202	0.711	2.313	2.491
30.00 (PS)	-0.015	-3.729	3.790	1.040	2.573	2.751
40.00 (PS)	-0.832	-4.495	4.015	1.336	2.604	2.679
50.00 (PS)	-2.014	-5.688	3.991	1.593	2.540	2.398
60.00 (PS)	-3.889	-7.710	3.779	1.801	2.450	1.979


Stability curve
Max. GZ at 30º or greater=2.762
Angle of max GZ=32.5º
GM=11.067
Righting lever (m)
Heeling angle (Degr.)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60

Appendix 7.1 Liebherr CBW Crane price email

Dear Mr Gort,

Referring to your request for information we herewith submit you some information about the various crane sizes of the CBW-type crane.

Standard is the crane equipped with a cabin fix installed under the jib.

For reason of better view (on top of containers) and keeping the airdraft of the crane/vessel as low as possible both cranes installed on the Mercurius inland container vessels are equipped with a side mounted elevated cabin system.

The crane can be equipped with fix or telescopic spreaders which gives a serious price difference in crane and spreader attachment. Advantage of telesciopic sspreadr means no changes of frames in case mixed 20 ft, 30 ft and 40 ft spreaders have to be handled. Also can the telescopic spreader be equipped with a centre of gravity compensation system.

A set of fix spreaders (20 ft +40 ft) frames costs approx EUR 40,000,--, whereby one telescopic spreader cost approx Eur 125,000.—

The crane price vary with the size of the crane as you will inderstand,

The smallest basic crane costs approx. EUR 450,000.-- and the biggest approx EUR 600,000,--

For additionals you have to calculate approx EUR 75,000.—

Hereunder you will find some GA drawing (with c.o.g. of main componets of crane) in PDF together with the power outline diagrams.

<<CBW35(30)_24(30)-G.A drawing.pdf>> <<CBW 40_38-G.A. drawing.pdf>> <<CBW 45(40)33_24(28)32-G.A. drawing.pdf>> <<Power outline diagram - CBW 35(30)_24(30)-140 kW-400 V.pdf>> <<Power outline Diagram - CBW 45(40)33_24(28)32-195 kW-400V.pdf>> <<power outline diagram- CBW 40_38- 220 kW-440 V.pdf>>

And in dxf/dwg format for the two biggest size crane, Please adjust jib length to the required max reaches as given above.

<<2980 I - prel. CRANE-GA_CBW 100(50)-12(28).dwg>> <<2640 I HD - CBW 60(40)30 16(26)31.zip>>

Trust this meet your requirements and please contact ius if additional information is required.

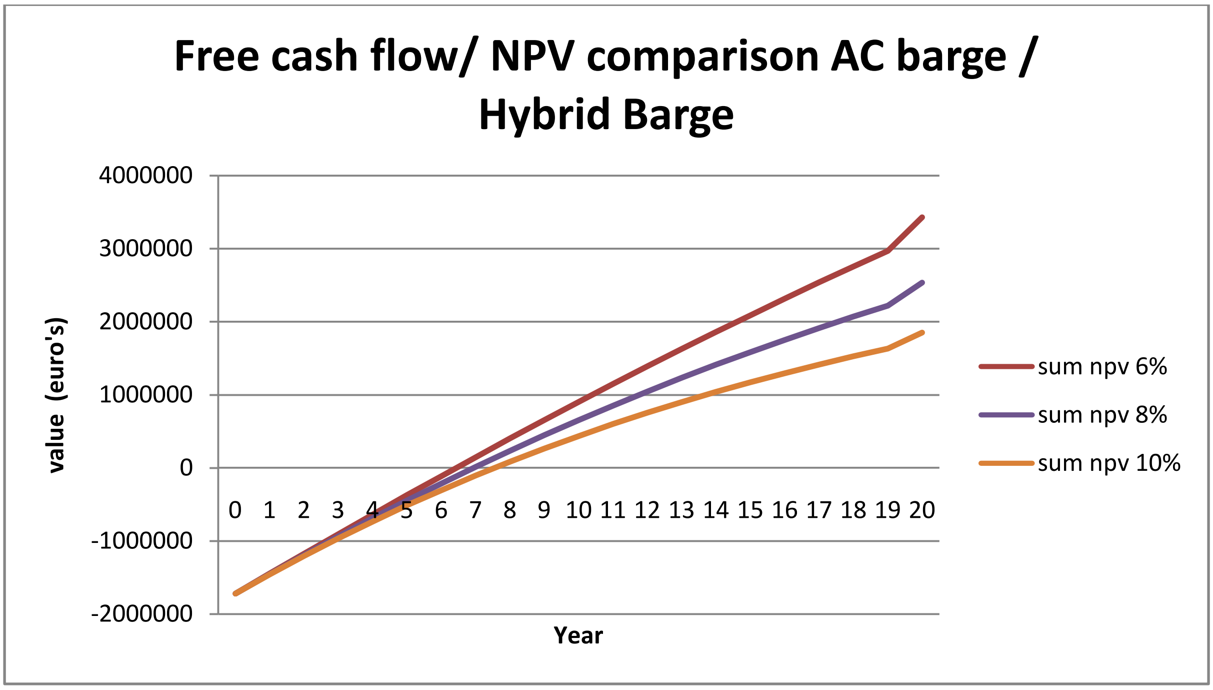
With best regards,

Arie PUNT

SALES MANAGER

Liebherr Maritime Benelux B.V.

Appendix 7.2 Influence NPV rate



Appendix 7.3 Cash flow calculation

	Year	0	1	2	3	4	5
	investment barge	-€ 1.722.802					
	price_cont		€ 51	€ 53	€ 54	€ 56	€ 57
1	turnover		€ 1.722.218	€ 1.773.884	€ 1.827.101	€ 1.881.914	€ 1.938.371
	operational cost_cont		€ 29	€ 30	€ 31	€ 32	€ 33
	cont_year		33769	33768,97749	33768,97749	33768,97749	33768,97749
2	cost_year		€ 995.744	€ 1.025.616	€ 1.056.384	€ 1.088.076	€ 1.120.718
3=1-2	EBITDA		€ 726.474	€ 748.269	€ 770.717	€ 793.838	€ 817.653
4	depreciation		€ 229.707	€ 229.707	€ 229.707	€ 229.707	€ 229.707
5=3-4	Operational result		€ 496.767	€ 518.562	€ 541.010	€ 564.131	€ 587.946
6	interest costs		€ 120.596	€ 120.596	€ 120.596	€ 120.596	€ 120.596
7=5-6	pre-tax result		€ 376.171	€ 397.965	€ 420.413	€ 443.535	€ 467.350
8	tax		€ 112.851	€ 119.390	€ 126.124	€ 133.060	€ 140.205
9=7-8	Return after tax		€ 263.320	€ 278.576	€ 294.289	€ 310.474	€ 327.145
10=9+4	cash flow		€ 493.027	€ 508.283	€ 523.996	€ 540.181	€ 556.852
11	repayment		€ 200.994	€ 200.994	€ 200.994	€ 200.994	€ 200.994
12=10-11	free cash flow	-€ 1.722.802	€ 292.033	€ 307.289	€ 323.003	€ 339.188	€ 355.858
	disc cash flow	-€ 1.722.802	270401,08	263450,90	256410,01	249313,17	242191,26
	sum npv	-€ 1.722.802	-€ 1.452.401,27	-€ 1.188.950,37	-€ 932.540,36	-€ 683.227,19	-€ 441.035,94
	rate	1,08					
		7,0	years to NPV=0				
	NPV after 20 years	€ 2.553.609,55					

6	7	8	9	10	11	12	13	14
€ 59	€ 61	€ 63	€ 65	€ 67	€ 69	€ 71	€ 73	€ 75
€ 1.996.523	€ 2.056.418	€ 2.118.111	€ 2.181.654	€ 2.247.104	€ 2.314.517	€ 2.383.952	€ 2.455.471	€ 2.529.135
€ 34	€ 35	€ 36	€ 37	€ 38	€ 40	€ 41	€ 42	€ 43
33768,97749	33768,97749	33768,97749	33768,97749	33768,97749	33768,97749	33768,97749	33768,97749	33768,97749
€ 1.154.340	€ 1.188.970	€ 1.224.639	€ 1.261.378	€ 1.299.220	€ 1.338.196	€ 1.378.342	€ 1.419.692	€ 1.462.283
€ 842.183	€ 867.448	€ 893.472	€ 920.276	€ 947.884	€ 976.321	€ 1.005.610	€ 1.035.779	€ 1.066.852
€ 229.707	€ 229.707	€ 229.707	€ 229.707	€ 229.707	€ 229.707	€ 229.707	€ 229.707	€ 229.707
€ 612.476	€ 637.741	€ 663.765	€ 690.569	€ 718.177	€ 746.614	€ 775.903	€ 806.072	€ 837.145
€ 120.596	€ 120.596	€ 120.596	€ 120.596	€ 120.596	€ 120.596	€ 120.596	€ 120.596	€ 120.596
€ 491.880	€ 517.145	€ 543.169	€ 569.973	€ 597.581	€ 626.018	€ 655.307	€ 685.475	€ 716.549
€ 147.564	€ 155.144	€ 162.951	€ 170.992	€ 179.274	€ 187.805	€ 196.592	€ 205.643	€ 214.965
€ 344.316	€ 362.002	€ 380.218	€ 398.981	€ 418.307	€ 438.212	€ 458.715	€ 479.833	€ 501.584
€ 574.023	€ 591.709	€ 609.925	€ 628.688	€ 648.014	€ 667.919	€ 688.422	€ 709.540	€ 731.291
€ 200.994	€ 200.994	€ 200.994	€ 200.994	€ 200.994	€ 200.994	€ 200.994	€ 200.994	€ 200.994
€ 373.029	€ 390.715	€ 408.931	€ 427.694	€ 447.020	€ 466.926	€ 487.428	€ 508.546	€ 530.298
235071,63	227978,43	220932,90	213953,63	207056,79	200256,41	193564,52	186991,38	180545,66
-€ 205.964,31	€ 22.014,13	€ 242.947,03	€ 456.900,66	€ 663.957,45	€ 864.213,86	€ 1.057.778,38	€ 1.244.769,76	€ 1.425.315,42

15	16	17	18	19	20
					€ 1.148.535
€ 77	€ 79	€ 82	€ 84	€ 87	€ 89
€ 2.605.009	€ 2.683.159	€ 2.763.654	€ 2.846.564	€ 2.931.961	€ 3.019.919
€ 45	€ 46	€ 47	€ 49	€ 50	€ 52
33768,97749	33768,97749	33768,97749	33768,97749	33768,97749	33768,97749
€ 1.506.151	€ 1.551.336	€ 1.597.876	€ 1.645.812	€ 1.695.187	€ 1.746.042
€ 1.098.858	€ 1.131.823	€ 1.165.778	€ 1.200.751	€ 1.236.774	€ 2.422.412
€ 229.707	€ 229.707	€ 229.707	€ 229.707	€ 229.707	€ 229.707
€ 869.151	€ 902.116	€ 936.071	€ 971.044	€ 1.007.067	€ 2.192.705
€ 120.596	€ 120.596	€ 120.596	€ 120.596	€ 120.596	€ 120.596
€ 748.554	€ 781.520	€ 815.475	€ 850.448	€ 886.471	€ 2.072.109
€ 224.566	€ 234.456	€ 244.642	€ 255.134	€ 265.941	€ 621.633
€ 523.988	€ 547.064	€ 570.832	€ 595.314	€ 620.529	€ 1.450.476
€ 753.695	€ 776.771	€ 800.539	€ 825.021	€ 850.236	€ 1.680.183
€ 200.994	€ 200.994	€ 200.994	€ 200.994	€ 200.994	€ 200.994
€ 552.701	€ 575.777	€ 599.546	€ 624.027	€ 649.243	€ 1.479.190
174234,55	168063,95	162038,60	156162,17	150437,40	317357,46
€ 1.599.549,97	€ 1.767.613,92	€ 1.929.652,52	€ 2.085.814,69	€ 2.236.252,09	€ 2.553.609,55