INLAND SHIPPING & CONTAINER HANDLING

FEASIBILITY STUDY ON SCALABLE INLAND CONTAINER TRANSPORT AND TERMINAL CONCEPTS

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by

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Summary

Container transport is currently the largest growth sector for the deep-sea ports in Amsterdam, Rotterdam, and Antwerp (ARA). Both the number and weight of containers increase as the globalization of production and consumption continues. The never-ending inflow and outflow of containers in these deep-sea ports relies heavily on hinterland transport. For the ARA ports, this hinterland network closely follows the basin of the Rhine and is therefore referred to as the Blue Corridor. Within this network, truck haulage transports the largest share of containers and both (partially) causes and suffers from congestion. Additionally, congestion results in excessive emissions. Inland shipping is the second largest container transporter. This mode is far less prone to congestion, because waterways have growth margins of approximately 700% and substantially fewer external costs. To keep the Blue Corridor habitable in terms of accessibility (congestion) and to limit the external effects of transport (a.o. emissions), container hinterland distribution should be mode shifted (to a large extent) towards inland waterway transport (IWT).

In the container navigation market as it currently operates, large vessels are used to efficiently transport large quantities of containers on the large waterways such as the Rhine and the Meuse. At the same time, however, these large vessels are heavily limited by their size because they are unable to penetrate the capillaries of the waterway network. The result is that although their main waterway navigation part is very efficient, the container requires handling/transshipment at an inland transport. After/before it is unloaded, the container has to go to/come from the client, who is only accessible by truck in its current shape. Both handling and pre-haulage and post-haulage (PPH) are complex, time-consuming, and costly additional manoeuvres.

The main question is formulated in order to guide this research. Here feasibility is defined as automated, simplistic, competitive, and profitable during the process steps of cargo transport, storage, and handling. Small vessels and small inland waterways are both defined as CEMT ≤ IV. Cargo of interest is the containerized goods market.

Can a feasible design for both ship and terminal be designed that can revitalize small vessel transport on small inland waterways, and if so, what will this design look like?

To find potential improvements for this current method of container distribution and collection modes, containers and terminals are analyzed. Beginning with the former, IWT has superior cargo carrying capabilities when it comes to high volume transport. One inland Rhine-size vessel, with a small crew, carries volumes upwards of 200 TEUs (20-foot equivalent units). Compared to a truck with one driver that can only carry as much as one or two TEUs, IWT can reap benefits from what are known as economies of scale (EoS). The results of these EoS are especially visible over longer distances, where the IWT alternative operates at significantly lower costs compared to truck haulage. The latter is superior for short distances ≤ 100 km and low volumes, because the road network is denser and requires less time. Similar to this cost difference, there is a substantial difference in external effects. Whereas transport by truck leads to accidents, noise, congestion, and significant pollution from exhaust gases, IWT only causes air pollution via exhaust gases. With the low navigating speed of IWT and the large transport volume made possible, the overall external effect per container is only a fraction of that of truck haulage. Reducing congestion and harmful emissions caused by truck can best be done by decreasing the required truck haulage distance. Penetrating the capillaries of the waterway network and operating rural terminals can ensure lower trucking distances.

The large CEMT Va vessels are specially designed for container transport. Articulated trucks can be equipped with special container trailers. There are not, however, currently any small inland vessels that are specifically designed for container transport. On average, the maximum attainable loading degree for the four smallest classes as defined by the CEMT is 76% in terms of volume and 45% in terms of payload. When these sub-optimal vessels are used to compete against the current competition, it is clear that they operate at substantial deficit. Their loading degree automatically means that costs per container will be higher than strictly necessary. A handful of concepts and/or dedicated vessels are currently known, but none of these have been able to really successfully operate within the market.

Containers can vary in both size and weight, but they all rely on their mutual dimensional denominator in the form of corner castings. This allows for easy handling and mixed use. Two TEU containers take up the same amount of space as one 40-foot equivalent unit (FEU) container. Special container types such as tanktainers and pallet-wide containers (PWCs) are used far less often than standard boxes are. The PWC in particular is currently only used for truck haulage and rarely for inland shipping.

Both the cost of using a container (€4 per day) and the time value of the goods inside (€9 per day) are limited compared to the total cost of transport between the hinterland and an ARA port; however, margins are small and competitive advantage can depend on mere euros. Incorporating these costs is the best and most accurate method.

There are many sizes of inland terminals throughout the Rhine delta. A wide-span gantry crane is used in the most common current layout. This crane handles the vessel and arranges the stack facility. A reach stacker is used for additional container handling maneuvers. The required start-up investment for these terminals is substantial and results in a very high cost per box. The larger inland terminals become, the more efficiently their equipment is used. As a result, their handling costs per box decrease. The current accepted market cost level is approximately €60 per box. Terminals with annual throughput volumes ≤ 50,000 TEUs have only one option to lower their costs, which is to increase their annual volumes. At a small-scale terminal like the concept terminal designed in this thesis, such growth is undesirable. Revolutionary terminal designs are therefore required.

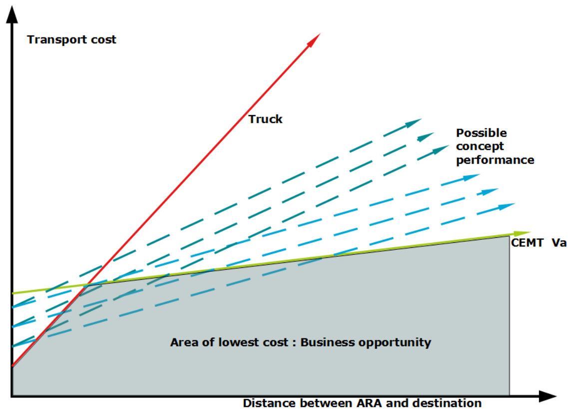
These terminals should focus on four aspects: investment cost, operating cost, throughput capacity, and risk & reliability. The investment costs are one-time expenses, but since these costs are partially financed by a loan, they will be recurring for a long period of time. Operating expenses are incurred each year. Complex manned operations demand highly skilled crew that is inevitably expensive. Capacity determines the storage requirement and thereby requires equipment for operations. At the same time, this will prevent bottlenecks in the operations and enable smooth interaction between vessel and terminal and between truck and terminal. Risk and reliability incorporate (temporary) loss of operation and complexity-induced down time.

Combining the individual markets demonstrates that truck haulage is a quick, low-cost solution for short distances. Large vessels automatically make large calls and/or many calls per voyage. Economies of scale cannot mitigate high handling times over short distances. Long-distance transport results indicate that large-scale IWT can mitigate the call-out costs and therefore reap EoS. The truck haulage alternative remains superior in terms of flexibility and speed, but costs increase rapidly over the distance. For distances greater than 200 km, the realized average speed remains constant. Doubling the distance requires twice as much travel time and therefore results in double transport costs. Truck haulage cannot achieve any EoS for distances above 200 kilometers.

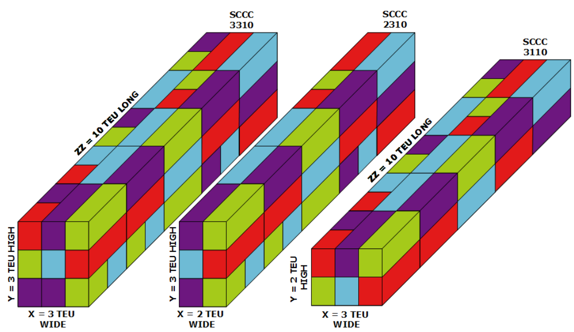
For small-scale inland shipping, the call-out costs are higher than for a truck but lower than for a large inland vessel. With increasing distance, the small scale is able to create EoS that are, however, of limited effect in keeping with the limits of the vessel's size. Figure 1a illustrates the transport cost for the truck and large-scale inland vessel competition (CEMT Va). Smaller concept vessels will generate transport costs more comparable to those of a truck, which is reflected by the dark green lines. Increasing the size will allow for more EoS, as the light blue lines indicate.

For the concept to be potentially profitable in terms of a sustainable business case, the cost level has to be below that of existing competition. This area is highlighted in grey. It is apparent that the concept vessel might be able to operate within a certain range of distance with costs below those of the competition. Operating the wrong vessel at the wrong distance leads to costs above current competition levels. No sustainable business case can exist for such cost levels.

These concepts, however, are nonexistent. As a result, the Scalable Container Carrier Concept (SCCC) is developed, which is a series of inland vessels built around their cargo, the container. The format of the SCCC is *"XYZZ"* which is indicated by Figure 1b. X indicates the hold width in TEUs, Y the stacking height, and ZZ the hold length. By creating a modular series designed with precise dimensions in order to accommodate an integer number of containers, it is possible to avoid voids in the hold. The vessel is thus precisely large enough. Depending on cargo demand, market conditions, and navigation limitations such as sluice dimensions and available air draught, the maximum vessel size can be selected. The result is that the proposed concept is of optimal design, has the lowest possible build and operating costs, and is the best equipped to face competition for a new-build inland vessel.



(a) Impression of transport cost development over distance for competition and concept.



(b) Classification clarification for the SCCC

Figure 1: Summery supporting figures.

In cooperation with the inland vessel, a revolutionary concept terminal is developed. This scalable container handling concept (SCHC) is based on four key aspects. A ship-based gantry crane that rides the hatch coaming is based on existing hatch crane technology. Containers are transported across the terminal using a rolling conveyor system. This type of handling is currently found in parcel logistics, but a heavy-duty application is deemed structurally feasible. Finally, the containers are stored using a rack system that prevents reshuffling and stack rearrangement moves. These moves are common at existing terminals but are inefficient and costly. A fixed gantry crane completes landside transfers, enabling efficient interactivity with the truck and its container. The result of the cooperation between these parts is a small-scale terminal able to operate at lower costs than existing terminals. Costs per container are primarily dependent on the annual throughput volume and the corresponding terminal investments.

Analyzing the (cost) performance of both the SCCC and SCHC indicated the importance of and sensitivity to several parameters. For the SCHC, it was determined that the call frequency should be as high as possible. This reduces the required investment, decreases terminal dimensions, increases utilization of equipment, and therefore reduces the cost per container. The minimum competitive terminal size is approximately 10,000 containers (boxes) per year. At lower annual throughputs, operating costs have to be divided among too few containers. Whereas current inland terminals are advised to grow as soon as possible to an annual throughput of 30,000 boxes (50,000 TEUs), this limit has been lowered to 18,000 boxes per annum for the SCHC. Competitive handling rates are achieved at 60% of the annual volume a competitor requires.

The SCCC performance analysis demonstrated the importance of size. Selecting too small of a vessel means that while it can operate at full loading conditions, it fails to lower costs by creating EoS. Overshooting and selecting a vessel that is too large leads to high costs per load and a loss of economies of scale. In most cases, the value of time is very low for inland shipping containers. Slow navigation is therefore advised in such cases. How slow depends on the distance and desired call frequency. Operating a five-day per week sailing scheme creates the weekend as a limit. It is economically efficient to increase the speed to be able to make the voyage within the five days; however, when the (round) trip cannot be made within the five days, increased working hours are advised.

Including a 24-hour ARA handling time and an eight-hour inland terminal handling time, the weekly sailing cut-off distance is approximately 350 kilometers. Sailing as far as possible within this span led to the decision to research a favorable case in Ladbergen, Germany. This small town is located near the Dortmund-Ems canal, which allows for CEMT IV navigation. Ladbergen is located in the triangle of Münster, Osnabrück, and Bielefeld. This area is expected to generate at least 18,000 TEUs (12,000 boxes) per year based the on the number of residents and the regional Gross Domestic Product (GDP).

The results indicate economic feasibility for both the SCCC and the SCHC. Air draught limitations due to fixed bridges on the canal lead to problems when transporting high-cube containers. Using a longer SCCC can (partially) mitigate this problem. Smart shipping cost allocations for TEU, FEU, and high-cube containers leads to cost competitive operations.

Operating the SCHC terminal in Ladbergen and transporting 18,000 TEUs (12,000 boxes) per year to and from Rotterdam with two SCCCs leads to lower costs of transport for all container sizes. At a very competitive price point the net present value of the total investment is €4 million for 15 years of operation after 6% annual discounting. The highest competitive price will lead to an even larger net present value. Determining the exact price point will have to include the resistance of changing transport alternatives, but this is outside of the scope of this thesis. As a result, no exact price point or resulting maximum net present value is studied.

Results from the favorable case demonstrate sustainable feasibility. The primary research question can therefore be answered positively. Penetrating the capillaries of the inland waterway network within the Blue Corridor, thereby reducing the need and costs of additional PPH, is economically and technical feasible. When the SCHC is located at the right location, the PPH distance currently required to reach an existing terminal can be radically reduced. Pre-haulage and post-haulage are both expensive and cause many negative external effects. A reduction of this distance is therefore twice as interesting from a generalized cost perspective. For the favorable case monetized and discounted external effect savings add up to a NPV of €21.7 million over a 15 year period.

Analysing the sensitivity of the found results showed limited impact of financing aspects. Primary influencing factor is the annual throughput volume since this affects both the SCCCs and SCHC. In addition, the scalability of the SCHC in particular allows for optimal terminal dimensions throughout the start-up phase. This prevents excessive start-up losses that are difficult to make up for. Compared to existing non-scalable terminals, this is real cost saver. The scalable containers series enables automated container handling at minimal additional costs. Sailing costs are as low as possible under all conditions.

Preface

This thesis is the result of a nine-month effort to revive small waterway utilization. Container transport is one of the largest overall growth sectors, and because they usually contain consumer goods, their distribution to and from cities is significant. Providing scalable concepts maximizes the application potential throughout the Western European inland waterway network, which reaches many growing cities and towns. Increased use comes at the cost of marginal nuisance but with the benefit of offering a clean, efficient transport alternative to the current trucking industry. At the same time, it is understood that this goal cannot be achieved by this thesis alone . Many efforts have been made to find new business alternatives, but only a few have been able to make an impact on inland shipping. I therefore hope to demonstrate the hidden potential of container hinterland logistics with respect to small waterways and small annual flows.

I have to give credit to my daily supervisor, Koos Frouws, for introducing me to this amazingly interesting subject. His preliminary ideas helped to trigger my imagination and interest in this subject and to make sure the required scope was applied. The resulting size of this thesis is a good representation of the amount of interest and enthusiasm he has provided me with.

The man that is without a doubt responsible for my interest in the maritime shipping industry as a whole is Eddy van de Voorde. He was my professor during the first eight months of writing my thesis and I am very thankful for his insight, consideration and recommendations. Without his graduation management, the end result and quality of this thesis would not have been the same. His understanding of shipping markets has amazed me for a long time, and I am glad to have gained some of that knowledge.

Throughout my thesis research I was fortunate to share an office with Floris van Nievelt. His maritime background, the fact that he was writing his thesis at the same time, and his different perspective on several subjects allowed me to find a solution to some of my problems. I am thankful for his time, effort, and sincere interest. Similar gratitude goes out to Moos Meijer who allowed me to put results into perspective and in-between long hours ensured I took a break every now and then. Lastly I would like to personally thank Kevin Drenthe for his assistance with regards to the cover design and document lay-out.

I would also want to thank my friends from back home. Our lifelong friendship enabled great support when requested. Also their seemingly unending stream of small jokes triggered me to show my best during the writing of my thesis. Thanks guys.

On a personal note, I would like to express my gratitude for the support of my parents and two younger brothers. Their interest in my subject and graduation progress enabled me to reflect on and improve my work. Their continuous support allowed me to study for the past years and made me the man I am today. I am forever indebted for the opportunities my parents have given me.

Gerben Dekker
Woudenberg, November 2018

Contents

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List of Abbreviations

20 / 20"	Twenty-foot container
40 / 40"	Forty-foot container
40HC	Forty-foot High-Cube container
45" / 45HC	Forty-five-foot High-Cube container
a.o.	among other(s)
a.o.t.	among other things
A1	Operating scheme of 14h/5days per week
A2	Operating scheme of 18h/5days per week
ARA	Amsterdam-Rotterdam-Antwerp
B	Operating scheme of 24h/7days per week
c.q.	casa quo
CAPEX	Capital Expenditure
CBA	Cost-Benefit Analysis
CCNR / CCR	Central Commission for the Navigation of the Rhine
CEMT	Conference for European Ministers of Transport
CFS	Container Freight Station
CLC	Carriage Loader Concept
CMA	Current Market Analysis
CT	Container Terminal
CWA	Collective Wage Agreement
DEC	Dortmund-Ems Canal
DW	Deadweight
EBIT	Earnings Before Interest and Tax
EC / ec	External Cost
ETV	Elevating Transfer Vehicle
EU	European Union
EoS	Economies of Scale
FEU	Forty-foot Equivalent Unit
FSSC	Fixed Ship-to-Shore Crane
GC	Generalised Cost
GCA	Generalised Cost Approach
HC	High-Cube
HCGC	Hatch-Coaming Gantry Crane
IMO	International Maritime Organisation
IRR	Internal Rate of Return
ISO	International Organisation for Standardization
IT	Inland Terminal
IWT	Inland Waterway Transport
JIT	Just In-Time
LASH	Lighter Aboard Ship
LCL	Less than Container Loads
LHV	Long Heavy Vehicle
LW	Lightweight
MAFI	Company name formed by initials: Martin Fiala
MCA	Multi-Critiria Analysis
MCR	Maximum Continuous Rating
MDO	Marine Diesel Oil
MV	Motor Vessel
Mio	Million (euro’s)

NGICT	New Generation Integrated Container Terminal
NOVIMAR	European Novel IWT and Maritime Transport Concepts
NPV	Net Present Value
OHC	OverHead Crane
OOP / o.o.p.	Out-of-Pocket Cost
OPEX	Operational Expenditure
OT	Over Time
PPH	Pre- and/or Post-Haulage
PoR	Port of Rotterdam
PWC	Pallet-Wide Container
RCC	Rolling Conveyor Concept
ROI	Return On Investment
R&M	Repair & Maintenance
R&R	Risk and Reliability
RoRo	Roll-on Roll-off
RPN	Regulations for Rhine Navigating Personnel
SCCC	Scalable Container Carrier Concept
SCHC	Scalable Container Handling Concept
SCTC	Scalable Container Terminal Concept
SFC	Specific Fuel Consumption
SOLAS	Safety Of Lives At Sea
SSP	Saterday and Sunday Premium
SSS	Short Sea Shipping
TEU	Twenty-foot Equivalent Unit
tkm	tonne-kilometre
USP	Unique Selling Point
VGM	Verified Gross Mass
vkm	vehicle-kilometre
VoR	Value of Risk
VoT	Value of Time
WACC	Weighted Average Cost of Capital
WTA	Willingness To Accept
WTP	Willingness To Pay
XPC	X-Pack Concept
XYZZ	Size indicator for the SCCC series

I

Introduction

Part I

Yes, the container is the invention of the century

-

Bart Kuipers, 2014

1

Research Introduction

Section 1.1 contains the background of the thesis subject. Summarizing and extrapolating the background leads to the problem statement in section 1.2. The objective is accurately formulated in Section 1.3. The objective is directed by posing the primary research question, which can be found in Section 1.4. To be able to answer the question, the application of a particular scope is required. Section 1.5 describes the scope and its considerations. The activities are then proposed in order to guide the study. These activities are explained in Section 1.6. Finally, the research introduction ends with the reading guide in Section 1.7.

1.1. Background

Current road haulage operations face regular congestion challenges. This is especially the case for trucking across the Benelux, France and Germany [NOS economie redactie, 2016] [Wiget, 2016] [Chrétien, 2018]. Road transport already faces congestion related problems and will face even stronger congestion in the future [Graßer, 2014]. Congestion especially forms near urban areas, since the vehicle density is the greatest at these locations. Most consumers reside in these areas and they form either the beginning or the end of the transport chain. Consumption, the demand for consumer goods, triggers this transport.

Rail and water transport may be able to reduce the pressure on this modality . Congestion is usually rare in these modes of transport. With respect to rail, the potential is largely dependent on the region of interest. In recent times, articles have appeared stating that rail also faces congestion problems [3sat Mediathek, 2017] and has difficulty sustaining its modeshare [European Court of Auditors, 2016]. The growth of rail transport might also result in congestion on the tracks, because some sections of rail are already approaching their maximum utilization. As the first chapter in Part I indicates, rail has no natural infrastructure. This, together with expensive infrastructural expansion, limits the short-term growth capacity of rail.

With inland shipping having the greatest absolute growth potential - up to 700% according to the Port of Rotterdam [Port of Rotterdam, retrieved 15/02/2018], combined with its low pollution footprint [Planco Consulting GmbH and Bundesanstalt für Gewässerkunde, 2007] - it is ready to increase its part of the total transport across the region. Especially in a world with increasing environmental awareness the smaller pollution footprint of inland shipping is becoming increasingly interesting.

In order to maximize the attractiveness of inland shipping, the sector should innovate and further improve its services. Many reports regarding the future of inland navigation, smarter inland ships etc. have been written. These reports however often make use of the existing framework and try to achieve new optima. New data-driven pilots, such as Covadem [Covadem, consulted on 18/02/2018] with their real- time water level measurements and information systems, are intended to equip inland navigators with as much valuable information as possible. Other concepts that have been designed to revolutionize inland shipping include Watertruck [Watertruck+, 2018] and Portliner [FD, 2018].

The transportation solution offered by inland shipping is not necessarily a door-to-door service. When the origin and/or destination are not located near a sailed waterway, additional transport has to be used. Together, these transportation modes form the intermodal transportation chain. Changing between transport networks is conducted at inland terminals.

The handling of cargo at these locations is just as important to the total shipment process as the transport part is. There are large handling facilities at most deep-water ports, partly out of necessity, and partly because of economic viability. The total amount of cargo handled, as well as the peaks in processing, create an environment in which expensive, complex, and increasingly automated handling equipment can be used.

This advanced equipment is not readily available at inland terminals and quaysides. The throughput volume of cargo at these locations is far less than at the major deep-water ports. The handling peaks are also smaller because of the smaller ships used. This leads to a volume-driven limitation on feasible handling equipment. This limits the total “budget” for handling and in turn results in smaller, less advanced terminals. If equally expensive equipment was used at inland terminals, either the handling cost would be significantly higher, or the payback periods would be significantly longer. This would reduce the return on investment (ROI) for terminal operators. In practice, however, there would be no real ROI, because it is highly unlikely that anyone would choose a transport option that is significantly more expensive than the other options. Opening a terminal that is significantly overpriced will result in no substantial cargo flow over that terminal. There are simply far less expensive alternatives readily available.

Inland shipping is the primary area of interest within future cargo transport. In many reports, however, the future of small inland waterway transport (IWT) is depicted as hopeless. Smaller vessels are deemed inefficient, expensive, and undesirable. Comparing smaller vessels with larger, however is not so straightforward. In several cases, the profitability of smaller ships has been questioned when small vessels are compared with large vessels on large waterways. It is easy to deduce that economies of scale help large vessels to operate at lower rates, resulting in them outperforming smaller ships

In specific cases, however, the contrary is true. The very small Peniché, for example, is capable of making good money on the French canals. In such settings these ships outperform trucks, because they can carry ten times a truckload at an efficient price. Larger vessels cannot navigate these small canals. Rail-based alternatives are the only competition when present, but the absence of rail infrastructure means that the rail alternative cannot adequately reach the desired location. The Peniché has found its niche in this specific setting. It can then be deduced that the future of small IWT might lie in finding niche markets in which it stands a chance of outperforming competitors. Reports of difficulties in the Peniché market are usually caused by a lack of infrastructure maintenance. In Belgium, the Netherlands, and Germany, this is far less of an issue.

Automated operations are being widely discussed within shipping as a whole. As a result, inland navigation might also be an interesting application for advanced automation, enabling automated or unmanned operations. Since no real-world applications of automated or unmanned operations are currently in use, it might be interesting to find out what these technologies can do within this research area.

Part of the interest in autonomous and unmanned operations comes from the desire to lower costs. Additionally, inland shipping has increasing difficulty in attracting new personnel to the sector [Heerschop and Van Huizen, 2017]. Advanced operations can potentially reduce the need for an additional labor force, making it an interesting development to pursue.

1.2. Problem Statement

Distilling the background leads to the problem statement listed below. Road haulage is under pressure from congestion, environmental organizations, and policy/politics. Inland waterway transport has an abundant capacity to increase its market share . Operations in deep-sea ports are expensive, potentially creating room for cheaper alternatives bypassing these and that do not require such expensive equipment . Current transportation flows indicate that there is room for improvement. The small inland vessel's future is not as grim as many suggest, but its proponents should focus on finding niche markets or market segments in which small inland vessels can outperform their competitors. Automated operations are expected to make their entrance into the market in the near future, making them potentially interesting for inland shipping. The following problem statement can therefore be derived:

There is not currently an automated inland concept that focuses on transport of cargo with vessels on waterways (CEMT IV and smaller) with the ability to self-(un)load and be competitive with rail, road and large scale IWT.

1.3. Objective

The problem statement reveals a clear knowledge gap. Filling this gap leads to the following objective:

The goal of this research is to design a ship and corresponding terminal concept in order to decrease congestion. The concept must be automated, simplistic, competitive, and profitable during the process steps, transport, storage, and handling of cargo.

1.4. Main Research Question

This objective leads to the formulation of the main research question. By proposing and answering this primary question, the feasibility study becomes tangible and its goal becomes more concrete.

The main question is formulated as follows:

Can a feasible design for both ship and terminal be designed that can revitalize small vessel transport on small inland waterways, and if so, what will this design look like?

Here feasibility is defined as automated, simplistic, competitive, and profitable during the process steps of transport, storage, and handling of cargo. Small vessels and small inland waterways are both defined as CEMT ≤ IV.

1.5. Scope

The main research question leaves room for multiple types of cargo, corresponding equipment, and process steps. Whereas the explanations of the terms “feasible” and “small” narrow the subject down somewhat, further limiting the scope ensures a greater chance of success in finding a conclusive answer/solution. The applied scope consists of several limiters that are discussed in the following paragraphs.

As the background and the resulting problem statement indicate, inland shipping is only used for part of the total transportation chain. In an intermodal transport chain, transshipment of cargo is essential. Containerization is the number one enabler of transshipment and transport by a variety of vehicles and equipment types. Standardization in dimensions and maximum weight make cargo uniform. The researcher has therefore chosen to focus solely on container transport in this thesis. Large-scale adoption of containers has been in vogue since the invention and standardization of dimensions in the 1950s and 1960s [Levinson, 2010]. Containerization of goods is still increasing. A major advantage of the container lies in its dimensions and easy movability.

This thesis focuses on small vessels navigating small inland waterways. Roughly 65% of the waterway network throughout Western Europe consists of CEMT IV or smaller waterways [Buck Consultants Rotterdam, 2008]. A concept focusing on these waterways can cover a large area and penetrate the capillaries of the network. The Western European waterway network, most often referred to as the Blue Corridor, is therefore chosen as the region of interest.

There are not currently any self-serving inland container vessel concepts apart from the crane vessels from Mercurius Shipping [Mercurius Shipping Group, retrieved 12/07/2018]. As a result, dedicated container vessels are considered, using current non-dedicated ships as references. The ships are categorized according to their loading capacity. The concepts are based on a scalable modal. Scalability will prevent tailoring to one specific case at the cost of cannibalizing others. Both the ship design and the terminal design are left variable in dimension. The combination of both working together is of great importance.

Since intermodality requires handling, the study focuses primarily on enablers of container handling. The terminal and its equipment are therefore of interest. By incorporating both the terminal and the transporter (vessel), it is possible to prevent either one from being unnecessarily limited by the problems of the other . Keeping the terminal design scalable prevents affixing solutions to a specific case. Future outlooks provide an image of further automation and autonomous and/or unmanned operations. These future possibilities might turn out to be useful for the challenge posed by the problem statement. The researcher has therefore chosen to incorporate the effect and impact of these options.

Equipment-wise, solutions based on cranes are left out of this research as much as possible. Horizontal, gliding solutions are available, but have not been researched for these kinds of applications . Crane-equipped vessels have already been researched and even built, making that option better known and less interesting. If the first iteration is not feasible with a non-crane based solution, the crane will be researched for the ship portion of the designs.

The operational side of the terminal – including storage, dwell times, reliability, and risk – is all incorporated, because this determines the success or workability of the concepts.

The collaboration between inland vessels and trucks is incorporated, because this is expected to be a primary driver in the terminal’s operations. Rail is, however, mostly left aside. Trimodal operations are primarily located at locations with existing rail/water/road intersections. With the presence of all three relevant land-based modes, the volumes increase substantially. As a result, rail is left out because it is more difficult and less likely to interact with small-scale inland terminals. The existing IWT competitor is incorporated in the form of CEMT Va container vessels on the large waterways, which are currently competing with truck haulage for longer distance transportation. Risk, uncertainty, and sensitivity of systems and their operation is included in order to prevent the construction of a too-good-to-be-true scenario that is not workable in practice.

The effect of the concept on the market is studied in order to determine the “real” potential of the concept, meaning how the market will react at a certain price setting and how its reaction will affect the concept.

Whether or not the concept then outperforms rail, road, and/or large-scale IWT, and/or attracts new cargo for which it will become the preferred transport, is incorporated in the review.

1.6. Activities

Shaping the boundaries of the research is important to both separate primary and secondary issues, and to limit the total time required for this research. Following this research, insight should have been gained concerning the potential, implementation, operations, and costs of a novel container transport system. In order to achieve the most significant results, the following three primary iterative steps are followed:

- Current Market Analysis
- Construction & Evaluation of Concepts
- Feasibility Study in conjunction with a basic Cost Benefit Analysis

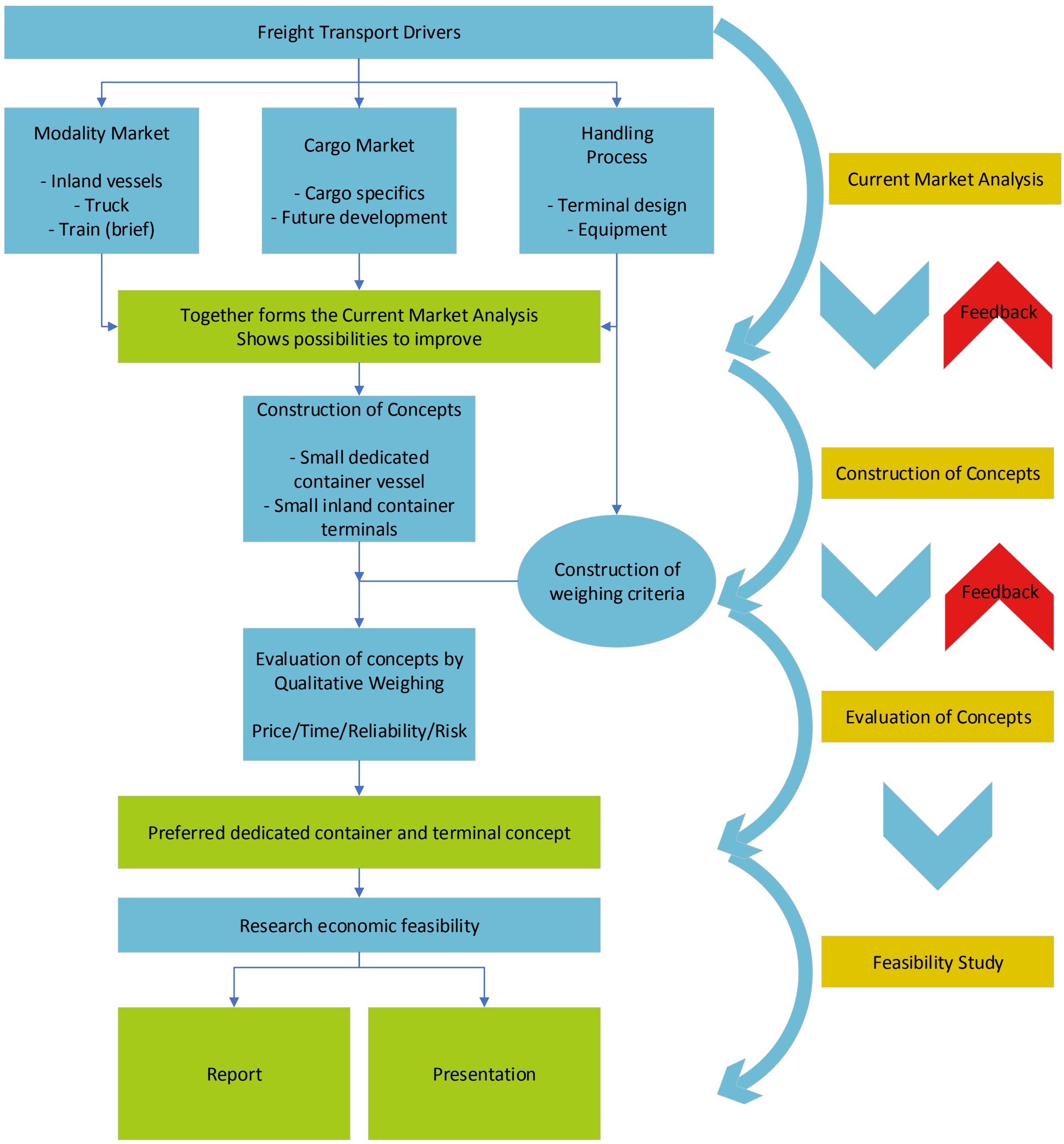


Figure 1.1: Schematic overview of research steps. [Source = own work]

1.6.1. Current Market Analysis

The three aforementioned steps are the backbone of this research. Before any improvements can be extrapolated/proposed, it is important to gain insight and understanding of both the current and future situations. These situations entail the transport modes, the container market, and the handling process. Understanding the drivers of current container transport is important to being able to understand the reasoning for the choices currently being made. The modality market is closely related to the infrastructure and cargo vehicles used on that specific network. By selecting the container, no truck changes have to be made. These vehicle specifics are therefore less important. Important specifications are incorporated when applicable, because they play their role in intermodal transport and handling. Part of the analysis of the different modes is considering their bottlenecks and limitations. Assuming that there is room for improvement, it is best to find out where this room is and what the corresponding effects would be. Examples of relevant boundaries will be presented during the specific chapters. The resulting analysis will provide the basis for the scalable mode solution for inland navigation.

The cargo market consists of two different subjects. First, the container's specifications are discussed in order to clarify what cargo the concept has to deal with. Important parameters include the amount of 20-foot equivalent unit (TEU) and 40-foot equivalent unit (FEU) containers, [1], the amount of High-Cubes and 45ers , the average and peak weights per container, available time for transport, and many more. Secondly, the cargo flows are analyzed. What containers are currently being used, and in what amount? How will this change over the coming years?

Finally, the handling process is analyzed. The first part contains the abstract terminal process. Translating this to the real world leads to a scalable overview of the required terminal parts. A distinction between intermodal and trimodal terminals is discussed. (Un)loading of containers can occur in many different ways. For now, the main point of interest is the cost associated with handling as a whole, since this makes up a large part of the total voyage cost. The equipment that is currently used at terminals is analyzed for effectiveness, future usability, and improvement potential.

Combining these three subjects, the current market analysis (CMA) is given shape. It contains information about the to-be-expected future container transport market concerning the competing modes, possibly required terminal designs, and cargo forecasts.

1.6.2. Construction & Evaluation of Concepts

It is important to use a holistic approach for the concept phase. In this context, "holistic" emphasizes the importance of the whole and the interdependence of its parts. If these improvements create a solution for one part while discarding currently working functionalities, the overall result might actually be a step back.

An important factor in the concept construction phase is that concepts should focus on a certain point dissociated from the others. This way, a wide variety of possibilities are researched, with a greater chance of incorporating a good option. The construction of concepts can make use of previous research in adjacent situations, such as short sea solutions [Wijnolst et al., 1993] that can be scaled down, and futuristic solutions from the 1990s that could now be realized. Added to that are concepts resulting from the previously made analysis, the subject of Part II, and information gathering.

The contents of this part consist of a small, dedicated inland container vessel (or series of such vessels) and a variety of terminal/handling concepts that each tackle one or more challenges arising from the CMA. Since a series of vessels is created, no selection has to occur. Different terminal concepts, however, hold individual strengths and weaknesses that require weighing.

All terminal concepts have to be feasible, meaning that they have to fulfill the minimum requirements stated by the definition of the feasible region. Concepts are weighed with the help of a multi-criteria analysis. The criteria and weight factors follow from the CMA section regarding handling. In turn, this leads to what is called the concept with the greatest potential.

The result of this section is a preferred terminal/handling concept. To limit the work during the concept design phase, selection is based on non-fully crystallized concepts. The concepts are therefore not fully engineered/detailed or market-ready. Fine-tuning and optimizing is done in the subsequent and final part of this research step. At the end of the construction and evaluation of concepts section, the dedicated container vessel (or series) and preferred handling concept are known and revealed.

[1] More information regarding abbreviations can be found in the List of Abbreviations

1.6.3. Feasibility Study in Conjunction with Cost Benefit Analysis

Before this stage, resulting concepts are unproven and are therefore further developed. The feasibility study finds its purpose in researching the total impact of new concepts, and the magnitude thereof. As stated on the cover of this report, a feasibility study is performed. In turn, the feasibility of the proposed concept tandem consisting of vessel(s) and terminal is studied. The technical feasibility is ensured in the previous part because only realistic, implementable concepts are proposed. The economic feasibility, however, is not analyzed until this point. The result is that this part studies whether or not and under what conditions economic feasibility is within reach. The concepts are designed to lead to a profitable business opportunity.

Part of the concepts' strength is a reduction in emissions and congestion when a mode shift from truck to IWT is made. These external effects, however, cannot all be written to the account of individual entities. These external factors cannot all be internalized in the generalized cost approach (GCA). By generalizing all facets of the transport option, a more fair/considered comparison can be made.

In an attempt to compare the concepts' impact on the overall transport system, a basic Cost-Benefit Analysis (CBA) is conducted. The CBA requires the internalization of all external factors, even those that cannot be internalized on the individual level. The result of the CBA is a valuation of the contribution the concept can deliver. It is to be expected that the concept will have a positive impact on the general transport sector. Performing a complete, detailed CBA, however, is a study on its own. As a result, only directly linked effects in external costs (ECs), such as pollution and congestion, are incorporated.

This thesis also explores whether or not some of the general benefits can flow towards the individual ship owner in the form of a credit and/or subsidy. Such a financial stimulation could either increase the profitability but could also be required to reach feasibility for the concept business case. The subsidy/credit than enables profitability leads to a sustainable investment for the community and/or the provider of the subsidy. After this section it is clear whether or not an individual feasible concept has been found and how this impacts the transport sector.

1.7. Reading Guide

The general structure of the report consists of five parts. First Part is finished after this reading guide and contains support and structure to the overall report. Please be reminded that before Part I the title page, summary, preface, contents, list of figures, list of tables and list of abbreviations have been presented.

Part II contains the current market analysis and thereby provides insight in the sub markets effecting future concepts. For experienced readers the introductions and intermediate conclusions for the Chapters 2 till 5 are sufficient to understand the current market analysis. Costs levels resulting from these four chapters lead to the contents of Chapter 6.

Next Part (III) contains the development of the inland vessel concept (Chapter 7) and inland terminal concept (Chapter 8). With both concepts being new both chapters are important to understand future parts of this report. Numerous figures depict both the vessel and terminal concept. The proposed design are accordingly researched for feasibility in the next part.

Feasibility evaluation is subject of Part IV. Different scenarios and the performance of the vessel and/or terminal concept for that case are analysed in Chapter 9. This chapter can be interpreted in two ways being it is either a justification for the scalable concept approach used in Part III or it can be seen as a method to fully understand the concepts performance under different circumstances. Either way Chapter 9 provides great understanding of the developed concepts their individual performance. Using both of the developed concepts in their most ideal application is subject of Chapter 10. Result being that after this chapter the reader understands and can reproduce the answer to the main question. Answering the research question is subject of the conclusion in Chapter 11. Recommendations for future research can be found in Chapter 12.

Supporting tables, figures, analysis and background information can be found in the appendices under Part V. The last appendix consists of the bibliography.

II

Current Market Analysis

Part II

In most transport networks, costs & lead-times are increasingly generated in the capillaries rather than in the arteries.

-

Woxenius & Bergqvist, 2011

2
Freight Transport

This first chapter focuses on the freight transport market. Any concept to be developed will have to operate in the current casa quo (c.q.) future market. A brief overview concerning the transport drivers and current situation is therefore provided, leading to a gain in market understanding with the possibility of identifying "operational windows" for future concepts. Sections 2.1, 2.2 and 2.3 discuss the current situation.

It is common practice to forecast a market after the current modus operandi is known. In this specific study, forecasting is extremely difficult and of minimal use due to the fact that no predefined case or operation is under review. The result of this is that providing a global forecast is almost certainly not directly applicable to an individual case, and specific forecasting might not be usable for other scenarios, making it of very limited use. This market forecasting is therefore left out as much as possible. The considerations regarding this decision, however, are discussed at the appropriate places.

Transport can be expressed in terms of total cost by using the generalized cost principle (GCA). The choice and usability of this approach are both explained. Important assessments for the implementation of this approach are under review in Section 2.4. An even more holistic view is secured by performing a basic cost-benefit analysis (CBA). This method is the subject of Section 2.5. The limited use of a forecast in this specific case is explained, and the choice to use the GCA and a CBA is justified. The intermediate conclusions that can be drawn are explained in Section 2.6.

2.1. The Blue Corridor

Most produced goods and/or extracted materials, either being raw goods, semi-finished products, or end products, do not originate at the geographic location of the end user. It is therefore necessary to move goods from their point of origin to their destination. This destination can be the end of the journey where the user is supplied with the good(s); however, it can also be an intermediate step where the good undergoes processing. Raw materials such as steel and plastics might undergo processing in order to become a semi-finished or finished product. The same goes for semi-finished products that are transformed into final products.

The digitalization of the world has made it easier than ever to order goods from anywhere in the world, with the possibility of them being delivered anywhere. The majority of world trade is performed with help of merchant ships sailing between the continents. With respect to the European Union (EU), seaports are very important for trade both with the rest of the world and within the internal market. 74% of imported and exported goods exchanged with the rest of the world, and about 37% of exchanges among EU member states, are transported through EU seaports [Pastori, 2015].

Figure 2.1: Inter-modal transport [Ekol, retrieved 22/02/2018]

The transportation of goods cannot take place without the use of a vehicle and its corresponding infrastructure, together forming a mode of transport. Chapter 3 provides an analysis of the relevant modes of transport that are used in this report.

The materials referred to in the first paragraph are together often quantified as goods. These goods, especially the (semi-)finished products, can be transported in multiple unit types. A large percentage of consumer goods are transported in containers as a result of the containerization experienced since the 1960's [Stopford, 2009] [Levinson, 2010]. Seagoing container carriers connect continents, providing transport links between the worlds deep-sea ports. In many cases, these ports are not the desired end locations for freight. It can therefore be concluded that deep-sea liners do not possess/provide the option of delivering the containers door-to-door. As a result, intermodal transport is required in the intercontinental transport journey from door to door. There is a whole field/network of freight transport to and from these deep-sea terminals. This region is often referred to as the service area, or hinterland, of a terminal. For continental container transport, more than one mode is often required/used, because not all sending and receiving parties are directly accessible via water.

Applying the scope to the container transport sector, transport that is of interest for this study takes place in a roughly contained area referred to as the Rhine delta. Throughout this region, multiple networks and modes are active including deep-sea ports; inland terminals; rail, road, and inland waterway networks; producer; and consumers. Figure 2.2 illustrates the course and drainage of the river Rhine. The area within the blue striped lines is of interest for the remainder of this report. Within this region of interest, there are many significant similarities in vehicles, voyages, and cargo. Next to that do rail, road, and IWT compete with each other across this region.

Looking back at the introductory chapter, no specific, predefined case is under review. As a result, concepts are not to be designed specifically for one or two scenarios. The concepts are to be developed, given a framework, and later matched to a potentially interesting location of use. Solutions discovered later in this study then have the potential to succeed throughout this region of interest. As Figure 2.3 illustrates, the majority of transport flows within the region, which makes it possible to find a feasible operational case for the concept.

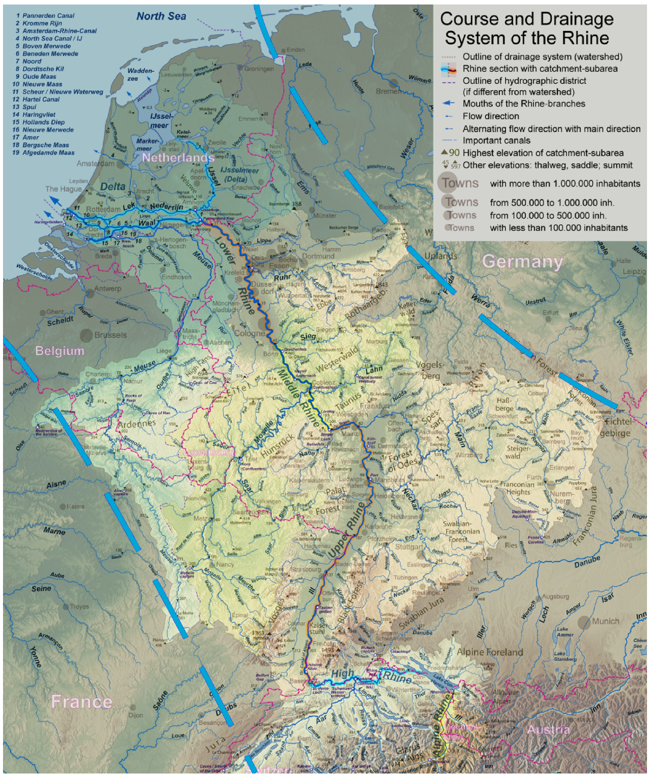


Figure 2.2: Course and drainage system of the Rhine. Added scope boundaries in blue. [WWasser, based on ICPR & RWS publications, 2013]

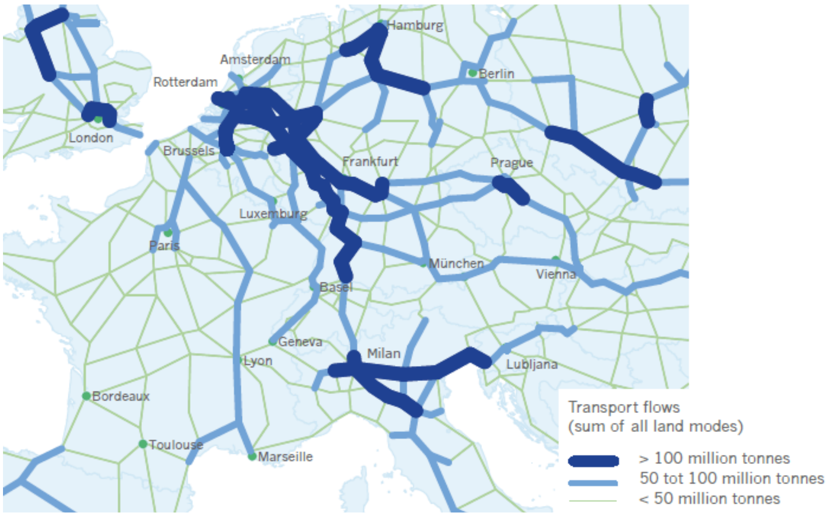


Figure 2.3: Transport flows (sum of all land modes). [Dutch Inland Navigation Information Agency, 2017]

Often referred to as the Blue Corridor, this delta has brought prosperity to the entire northwestern part of Europe. Figure 2.3 illustrates the sum of the continental transport flow over land, including rail, road, and inland shipping. This figure clearly indicates the significance of the region within the scope of this study. The Blue Corridor, so named because it follows the drainage of the Rhine, does not solely rely on waterways but also includes a vast amount of rail and road transport connecting the German Ruhr-area, Southern Germany, and the Alpine countries to the largest ports of continental Europe, which are the Amsterdam-Rotterdam-Antwerp (ARA) ports. Throughout the region, producers and consumers with diverse backgrounds are present in large quantities, providing a full range of needs and wishes.

2.2. Corridor-Bounded Transport

A variety of freight voyages take place throughout the region of interest. In general, there is transport that follows a strict, recurring timetable and there are spot voyages consisting of single and/or fixed numbers of trips [Konings, 2003]. For the inland container-shipping sector, the majority of transport between the ARA ports and the hinterland is on a time charter basis. The ship owner is contracted to sail between two or three ports in order to connect an inland terminal to its surrounding network. Voyage charter-based trips are more rare, since container transport often follows regular lanes and fixed timetables based on the ocean liners. Since inland vessels are, on average, not designed for a full lifecycle operating between the same locations, designs have to be more generalized so that they can be operated at multiple different areas.

With respect to this research, it is difficult to determine a specific market segment or type of trade that is of interest at this stage. Any to-be-developed concepts have to fit the current market characteristics, because these can be assumed rigid for the near-to-medium future. As a result, the chosen approach focuses on designing a concept that must in turn find a potential freight segment or niche in which it finds a profitable business case.

This research is not conducted for the sake of one particular transport case; therefore, there is little interest in what specific geographical journeys are currently undertaken. What is important is the distinction that those journeys are not of interest on the micro level, but can instead be valuable on the macro or general level, meaning that the share of those journeys in the total is of interest, as will become clear later on.

When a macro level distinction for currently occurring voyages is attempted, Figure 2.4 provides an abstract overview. Referring to the title of this section, "Corridor-Bounded Transport", it is interesting to understand why the current transport market is shaped the way it is. This analysis can then be used later on to explain whether or not a concept would be economically and/or technically feasible.

The abstract distinction consists of three separate voyage types. There are the indirect voyages, indicated with *a*, *a'* and *a"*, the direct voyage *b* and the potential voyage *c*. The reason that this subdivision is of interest follows from the choice of one of these voyage types.

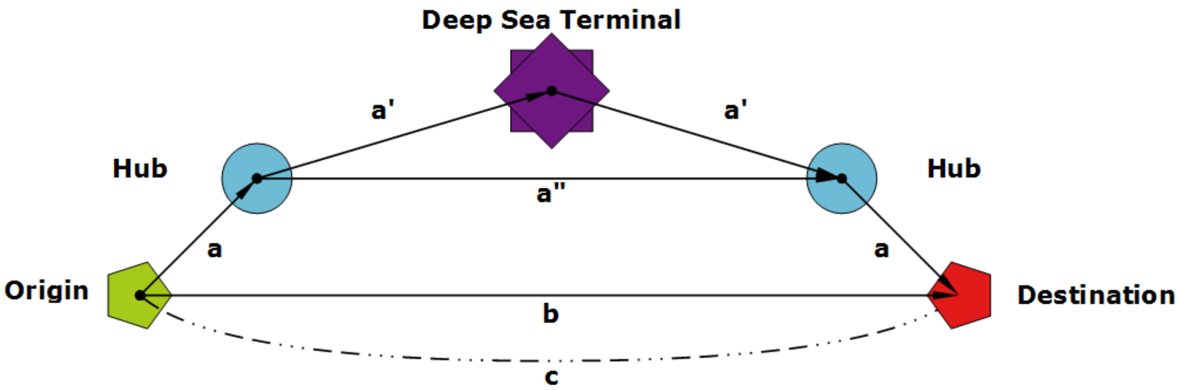


Figure 2.4: Abstract representation of multiple distinctive journey types. [Source = own work]

The first type is the indirect voyage (*a'*), which involves cargo being transported via hubs, deep-sea terminals, or large inland terminals. Figure 2.5 is a schematic representation of such a voyage, where a relatively small stream of containers might be present between origin and destination. Bundling this stream with others, economies of scale might be achieved, making it potentially interesting and (more) profitable for shippers to transport the cargo via a hub.

Correct bundling is, however, a reasoning based on equilibrium. Economies of scale (EoS) are not unlimited, but they are likely to find a certain optimum consisting of a fixed amount of cargo. For example, on the most common EoS in inland shipping involves crew requirements. Very roughly, a ship requires one captain no matter the size of the vessel. If the vessel becomes twice as large, the cost of a captain does not double, thus reducing the cost of having a captain per the amount of cargo. Economies of scale can be reaped by bundling cargos that are following the same trajectory for a significant part of the voyage. How this is organized determines the likelihood of success. When a large carrier first has to collect small parcels from multiple, far-flung locations, this part of the operation costs valuable time. The more small cargoes are bundled, the higher these bundling costs are, eventually becoming more disadvantageous than the EoS can make up for in the main body of the chain. Similar considerations occur on the delivery side of the voyage.

Another factor is that, when examining these often ARA port hubs, they are facing increasing congestion on their quays [Nicolai, 2017]. There is even a present thread of a reversed modal shift waiting to happen [Dijkhuizen, 2017a]. Why this is disadvantageous and what this is costing the shipping companies will become clear when discussing the generalized cost principle. Additionally, handling at such locations will become more expensive and time consuming, especially if volumes keep on growing at current rates. Given a certain capacity at the ARA ports, an increase in demand so that it is substantially larger than the supply is likely to lead to increased tariffs. It is also important to note that cargo is often taking significant detours. These scenarios indicate that there is clearly room for future improvement.

Although this first trip type may focus primarily on IWT, similar problems such as congestion faced by trucks near these hubs is also of concern. In most cases, these hubs grew organically out of a previous situation in which they were a local central point. Many of these hubs are located near urban areas, meaning that a significant percentage of the goods passing over these terminals are not originating and/or destined for that urban area, but rather to/from a more rural environment. Although it seems beneficial to operate this terminal, it might be more beneficial to remove part of this passing flow away from the urban area. The effect of having this cargo passing by presumably unwanted is discussed later in this chapter (see Section 2.4).

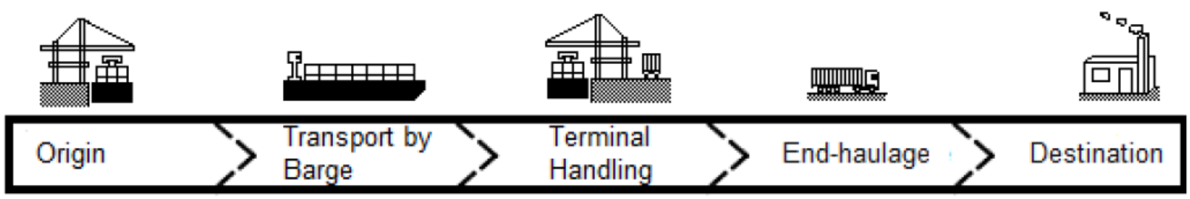


Figure 2.5: Example of intermodal IWT transport chain (type *a'*). [Van Dorsser, 2015]

Another distinctive freight transport type, indicated with *a″* in Figure 2.4, is also taking place yet far less frequently and with substantially less total annual volume. Voyages of this type are of great interest for this research for multiple reasons. Figure 2.4 indicates that this voyage type lies between direct, unimodal transport *b* and indirect, deep-sea terminal-using *a′*.

When a small number of containers require transportation with a possible irregular spread over time, unimodal truck haulage is currently used. In the other case, voyage *a′*, which involves regular, high-volume container demand, larger vessels can be used in order to potentially reap EoS. In many cases, these vessels are too large to be used on smaller, more direct waterways between hubs. From the moment the vessel is too large for the shortest route, there is no real limit to letting the vessel increase in size until the next boundary is in sight. This voyage type is thus in a tight squeeze between flexible truck haulage on one side and EoS on the other side. Figure 2.6 is a schematic representation of this voyage type.

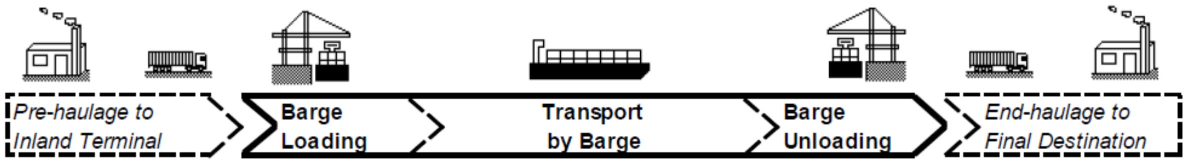


Figure 2.6: Example of competing intermodal transport chain (type *a″*). [Van Dorsser, 2015]

What both the previous voyage types have in common is the need for handling at one or more points in the chain. At the hubs, containers change carriers. This can be any combination of rail, road, and/or IWT. Handling locations, referred to as hubs and/or (inland) terminals, play a vital role in these transport chains. The handling process takes time, incurs costs, and brings extra risk and reliability to the chain. Each of these factors must be valued in order to determine whether or not this trip is truly more cost efficient for a load. Section 2.4 explains more about the valuation of these factors, and Chapter 5 goes into detail about this part of transportation chain.

The third voyage type is the direct, unimodal truck haulage indicated with *b*. This type of transport is flexible and fast but also more expensive, and it both causes and sufferers from congestion. Direct haulage is especially necessary when the origin and/or destination is far away from waterways, railway tracks, and/or inland terminals. In proximity to urban areas, such transport is deemed necessary because most consumers reside in those areas. On the other hand, the presence of large-volume road haulage is undesirable because it causes hindrances such as noise, emissions, and the dangers associated with large vehicles in populated areas. Such transport near urban areas that are neither the origin nor the destination is especially undesirable. The presence of such transportation puts a strain on the urban network and environment, even if that urban area can reap certain benefits it.

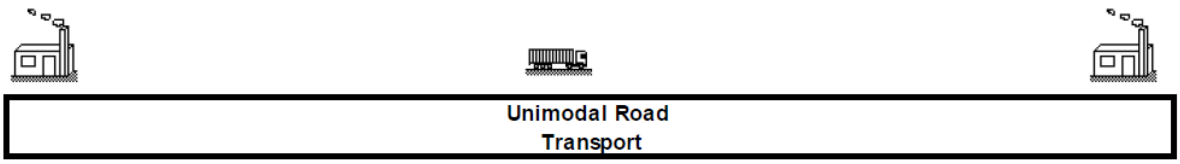


Figure 2.7: Example of standard solution with unimodal road transport (type *b*). [Van Dorsser, 2015]

There is one interesting type of transport that is not currently performed. There is cargo that has the potential to be transported at the right price but is not being transported accordingly. This flow or cargo is not taking place/exercised because of the absence of economically interesting transport, thus transport being too expensive given the clients' valuation. When goods can be sold elsewhere but the transport costs are too high, one is not likely to begin/keep transporting those goods. When the profit of additional sales is lower than the corresponding transport costs, this costs the producer money. Character *c* in Figure 2.4 indicates how such transport could be represented. Unlocking some of this potential could form a new niche market that has the potential to become (very) profitable.

The expressions frequently used when discussing transport are "intermodal," "synchromodal," "multimodal," and so on, indicating a difference in the use of modes. The words "intermodal" and "multimodal," for instance, are often intermingled and used interchangeably, creating the impression that they are synonyms. When comparing the exact definitions, however, there is an important difference, especially on the contracting side of things. For this study, the contracting specifics are not of interest and are considered outside of the study's scope. What is important is the additional meaning of the term "intermodal" when used in terms of containers. In that case, "intermodal" entails the ability to be carried by different modes of transport/conveyance without being unpacked/having the cargo physically handled. This understanding of "intermodal" is of interest, because the concepts created in this thesis are designed for intermodal container throughput.

In short, the following definitions of these terms are used throughout this research:

- Unimodal: Transport performed by use of one carrier throughout the entire transport chain.
- Multimodal: Transport performed by two or more different carriers of the same mode.
- Intermodal: Transport performed by two or more different carriers of two or more different modes.
- Synchromodal: Transport synchronously performed by two or more different carriers by two or more different modes.

Going intermodal is a choice that is not made without a good reason. There is no such thing as an all-around best option for a variety of reasons. Danielis and Marcucci [2007] have found an answer to the question of whether or not intermodal truck-rail freight transport could be a valid substitute for unimodal road transport by means of studying attribute cut-offs. Danielis and Marcucci [2007] have found the following:

The following seven attributes were considered: cost, transit time, late arrivals, loss and damage, flexibility, frequency and transport mode. It appeared that the minimum requirements regarding the attributes cost, late arrivals and damage and loss are quite strict for logistics managers, whereas they appear to be less concerned regarding transit time increases, as long as the shipment arrival is within the scheduled date. Shippers have little acceptance in risk of damage and loss of their freight (Danielis et al., 2005), but in general, intermodal IWT performs well in this area. Due to the growing social awareness on sustainability, shippers are increasingly focused on sustainability as qualitative aspect, especially the large shippers (NEA, 2010). Intermodal IWT transport has a low CO2 footprint compared to road transport, which makes it an attractive alternative if other service attributes remain largely unaltered. [Danielis and Marcucci, 2007]

It is to be expected that for intermodal IWT, similar if not the same attributes play a vital role in deciding to use IWT in the transport chain. These seven attributes can be used in the evaluation process of future concepts. The notice of adversity towards late arrival and damage and loss is a potential strength of small IWT. There is little or no congestion on waterways, whereas truckers experience congestion daily [Graßer, 2014]. Additionally, cargo is less likely to be damaged aboard IWT, because far fewer accidents occur, and the cargo experiences lower external loads and smaller accelerations.

The main driver for the choice of chain is, however, cost-oriented, because all of these attributes can be assigned a certain value. Assigning value to all relevant characteristics of transport is the basis of the GCA. With respect to the intermodal transport chains illustrated in Figures 2.5 and 2.6, the different parts of the chain all have their own characteristics. The GCA is the topic of Section 2.4.

2.3. Traffic & Transport

An impression of the undesirability of transport near urban areas might rise from the previous section. It is therefore necessary to clarify this briefly and highlight the distinction between transport and traffic. These two terms are not synonymous, but they are closely interrelated. Whereas transport refers to physical movement, traffic refers to the appearance of transport [Van Wee and Annema, 2014]. The first is often expressed in terms of transport performance in tonne kilometers. Traffic is most often expressed in kilometers per transport vehicle.

Both transport and traffic-related elements are of interest for the analysis of the different modes of transport. For instance, congestion is dependent on both transport and traffic. Transport comes from the need to move goods. The availability of infrastructure and many more factors then together form the traffic that carries out the transport. The success of IWT for the container sector is largely dependent on the presence of synchro-modal options [Van Riessen, 2018]. Offering synchromodal transport is inland shipping's best option for gaining interest and achieving the sector's goals of increasing its mode share in container transport. These conclusions are important for the evaluation of the concept(s) that occurs later on in this thesis.

Van Wee and Annema [2014] have also proposed a statement regarding the spatial distribution of traffic flow for a given amount of traffic. The three main influences are amount of congestion, traffic safety, and environmental footprint. Van Wee and Annema [2014] have introduced what they call the "resistance of moving." Introducing and incorporating this term is useful as this provides additional insight into transport motives. Choosing the mode of transport is dependent on this resistance, which is shaped by the following key factors: time of transport, cost of transport, comfort, safety, and (potentially) environmental impact. Later on, this is used when evaluating the concepts. Section 2.4 provides a more thorough valuation of transport. What is interesting about calling it the resistance of moving is the parallel that is easily drawn with everyday physics. If the driving force is greater than the resistance, one goes forward and will begin to move. Likewise, in the case of transport cost consideration, when the potential benefit (money to be made) outweighs the costs incurred, a profitable case is found and should be pursued.

Referring back to the background (see Section 1.1), the presence of freight-driven traffic near urban areas is becoming less desirable. Transport is not undesirable, because it is required to supply consumers in these areas. This study focuses on keeping transport intact or even making it grow while reducing the road-based traffic and inconvenience near urban areas. Currently, several cities have begun to ban some older road vehicles that are severe polluters from urban centers. It is to be expected that trucks will also eventually be prevented from operating near urban centers. New transport chains will therefore be required in order to maintain the supply. Expressing this in a "valued" sense would mean that the presence of traffic is valued differently. For certain cases, the value of not having trucks near a city center, for instance, has become greater than the value of having them; as a result, it is beneficial to ban trucks from that location. The next section explains this valuation more thoroughly.

2.4. Generalized Cost Approach

When comparing multiple different transport alternatives with their own tariffs, it is usually not only the out-of-pocket costs that are taken into consideration. Basing the comparison on more than direct cost alone is referred to as the generalized cost. In short, this method does not only take out-of-pocket cost into consideration but incorporates time, risk & reliability, and external effects. Monetizing these non-monetary cost factors and adding this all together leads to the generalized cost. The lowest generalized cost option is therefore the best/cheapest/most profitable transport solution available. When researching a new transport concept, the focus should not only be on having a competitive out-of-pocket tariff, but one should also take the non-monetary factors into consideration. The GCA is therefore incorporated into the present study.

2.4.1. Methodology

Up to this point, transport specifics such congestion, detours (excess covered distance), and handling have been discussed by not valuated. It is important to be notified of the fact that these are not necessarily to be avoided. For example, when a truck can avoid known congestion, whether or not it should do so is dependent on the possible gains. This is the result of what is known as the generalized costs comparison. In studies like this one, generalized costs are calculated for a variety of scenarios. The everyday decision-makers, however, do not necessarily calculate these costs on paper; instead, they often make a trade-off of some kind in their heads, weighing roughly the same parameters. As a result, thought is constantly put into decision-making based on the valuation of relevant factors.

The generalized cost approach consists of two parts: monetary costs and non-monetary costs [Button, 1993] (see Equation 2.1). Monetary costs, referred to as out-of-pocket costs, are those that physically have to be paid for, such as fuel and wear & tear. As the expression entails, these expenses have to be paid for in hard cash. For example, when an inland vessel is going for bunkers, the ship owners have to pay for these bunkers.

On the other hand, there are also non-monetary expenses during this process. Non-monetary costs refer among other things (a.o.t.) to the time spent undertaking a voyage. Other non-monetary costs include unreliability of travel time and/or time of arrival, frequency of operation, and the likelihood of having a container slot on a specific voyage [Koopmans et al., 2013].

Intangible factors, such as a reduction in undesirable emissions, can also be included in the generalized costs approach. For example, when a vessel is used to supply and distribute goods to a large facility instead of using 50 truckloads, harmful emissions are reduced. The willingness to pay for the reduction of these emissions, a.o.t. can be expressed in a beneficial value . Expressing them as a cost then affects the resulting outcome of the generalized costs equation. These costs also come back in the CBA described in the next section.

Adding monetary and non-monetary costs together cannot be done without equalizing the unit measures. Time, risk & reliability, and external effects are valuated by addressing the respective values of time, risk, and reliability. Other factors can be valued in their own specific ways in order to be expressed using euro-based values.

$$\textit{Generalized Cost} = \textit{Monetary Cost} + \textit{Non-Monetary Cost}. \tag{2.1}$$

The valuation of time, risk, and reliability, for example, reveals the challenge inherent in using this approach. Take for instance the value of time at which the "value" or "price" of an hour is approached . This can differ depending on the conditions. If a product can be sold today for €100 and tomorrow for €76, it depreciates/devalues €24 in 24 hours, or €1/hour. The value of time in this case is therefore €1/hour, since with every passing hour a value equivalent to €1 is lost. The same applies to, for example, personnel costs. Having a truck driver work overtime regularly costs 1.5 times his/her normal rate of, for example, €40. The boss can then value the truck driver's time at €60/hour. Similar techniques can be used to determine, estimate, or assume the value or risk, the value of reliability, and the value of external effects, also known as ECs.

$$\textit{Generalized Cost} = \textit{Out of pocket costs} + \sum_{i=1}^{n} Factor_i * V.o.F_i \tag{2.2}$$

Equation 2.2 outlines the generic form in which the generalized cost function can best be expressed [Button, 1993]. The monetary costs have been substituted by the out-of-pocket costs or expenses. Non-monetary costs are not limited by rules; as a result, which factors to include and which to exclude depends on the scope of the study. Generic writing then shows that these costs are a sum of all factors i, multiplied by their respective value. The summation is made for all values of i ranging between one and n, where n determines the number of factors included. If only time, risk, and reliability are to be taken into consideration, for example, n would be set to three.

The citation at the end of Section 2.2 demonstrates the impact of some relevant factors. Similar factors are found in Hanssen et al. [2012] and Bruzelius [1981] studies, justifying the use of such factors. One of these factors is the CO_2 footprint of IWT and the fact that it is of growing importance to ship owners. This means two things , the first of which is that the valuation of factors changes over time because awareness is changing. The awareness can increase or decrease as a result of different circumstances such as increased knowledge, effects becoming tangible, and/or a change in the policy/politics of the government and/or the client. Being "green" is currently considered a valuable unique selling point (USP), or even a requirement. Secondly, absolute levels are less important than the relative comparison that can be drawn. Some inland vessels have writing on the side stating that they replace a certain number of trucks that would otherwise cause a certain amount of congestion. The image shown to the general public, investors, and governmental organizations can be part of the success of IWT concepts.

2.4.2. Remarks

A remark concerning the generalized cost (GC) approach is also required. While time is an absolute given, the value of this time is dependent on many factors. As a result, this value is not uniform or absolute, but is subject to interpretation, estimation, and discussion.

When the GC method was first invented, it soon became widely used and misused. Valuing key factors in favor of a desired outcome led to a decrease in the reliability and accuracy of the method. For instance, the British government researched the applicability of the method [Grey, 1978]. Grey [1978] has placed most of the blame on falling into what he has called "index number traps," meaning that factors are given extra properties/valuation for which they where not designed. Grey has provided an example related to the indices of elasticity, emphasizing the importance of looking into both static and dynamic market development. For large variations, the basic GCA used to rely on linearized elasticities, leading to a misrepresentation of real-world, experienced behavior.

Current application of GC is widely respected and frequently used. Valuing the respective factors is completed more accurately, leading to more reliable valuations. For the valuation itself, it is important to provide reasoning for each value and to not keep the final result in mind in order to prevent biased comparisons.

2.4.3. Factors of relevance

Throughout this chapter, interesting, relevant, irrelevant, and indefinable factors have been mentioned. Summarizing the factors used in this study and categorizing them as monetary and non-monetary costs leads to the following list:

- Monetary Costs ⇒ Fixed & Variable cost
  - Operational Cost
    - Fuel
    - Crew/Labor
    - Repair & Maintenance
  - Capital Cost
    - Investment
    - Interest
  - Handling Cost
    - Handling charge
    - Port fees / port tariffs
  - Cargo Cost
    - Container Rent
    - Time value of cargo
  - Other Cost
    - Insurance
    - Tax
    - Overhead
- Non-Monetary Costs ⇒ Internal & External cost
  - Time
    - Navigation & Riding
    - Handling
    - Waiting
  - Risk
    - Short time loss of operation
    - Additional cost/time
  - Reliability
    - Long term blocked operations
    - Missing required time of arrival
  - External Cost
    - Congestion
    - Emission
    - Accidents
    - Other external cost

Referring to previously stated difficulties in defining the values, an effort is made to construct these based on available literature and personal estimation. Given the holistic approach, it is impossible to define exact values that would be equal across the entire region in the scope of this study. A scenario/situation-based approach is used to evaluate the concept. In doing so, the versatility of concepts is preserved, and a set of scenarios can be quickly examined.

This study is not the first to make an attempt at GC comparison. Al Enezy et al. [2017] have focused on developing a cost calculation model for inland navigation. They have strived for a modal taking into account internal fixed and variable out-of-pocket (o.o.p.) costs and EC elements. As stated in their abstract, company-specific input parameters are required for a fair and accurate comparison. The collection of averages and comparing with the corresponding industry average, however, can serve a scientific purpose. As Al Enezy et al. [2017] have stated, such an approach and its outcome can be used to analyze investment decisions, making this approach suitable for this feasibility study.

2.4.4. Impact of Decisive Variables

Going intermodal and bundling cargoes is a case of cost awareness. The different modes, different transport chains, and different operational profiles form a specific cost structure. Comparing trips *a"* and *b* from Figure 2.4, these differences lead to a difference in the cost buildup across the entire chain. For example, Figure 2.8 illustrates how the costs of unimodal truck haulage and an intermodal alternative compare.

Analyzing this figure provides additional insight into the buildup of costs along the distance travelled. All transport begins with starting costs. For instance, trucks have to be on time, leading to them often being somewhat early and thus waiting time; additionally, the truck has to drive towards the pickup location. These costs are fixed or a given regardless of the trips' characteristics later on, meaning that it does not matter how far the truck is going to drive; the costs incurred up until this point are uninfluenced by the journey to follow.

This means that at the moment the container is loaded on the truck, the container has covered no effective distance, but costs have already been incurred. If the truck then only drives 1 kilometer, the costs already incurred have to be counted against that 1 kilometer, making it an expensive kilometer. If the truck covers more distance, however, the relative contribution of each additional kilometer becomes less compared to the total cost, leading to a decreasing gradient in the figure. This is the reason that the *a*, *b* and *d* lines are curved, not straight.

The same principle is applicable to IWT. Call-out costs, waiting time, and the like are not dependent on the distance. The distance-dependent or marginal costs decrease over the distance, leading to the flattening out of the cost curve, as illustrated in Figure 2.8.

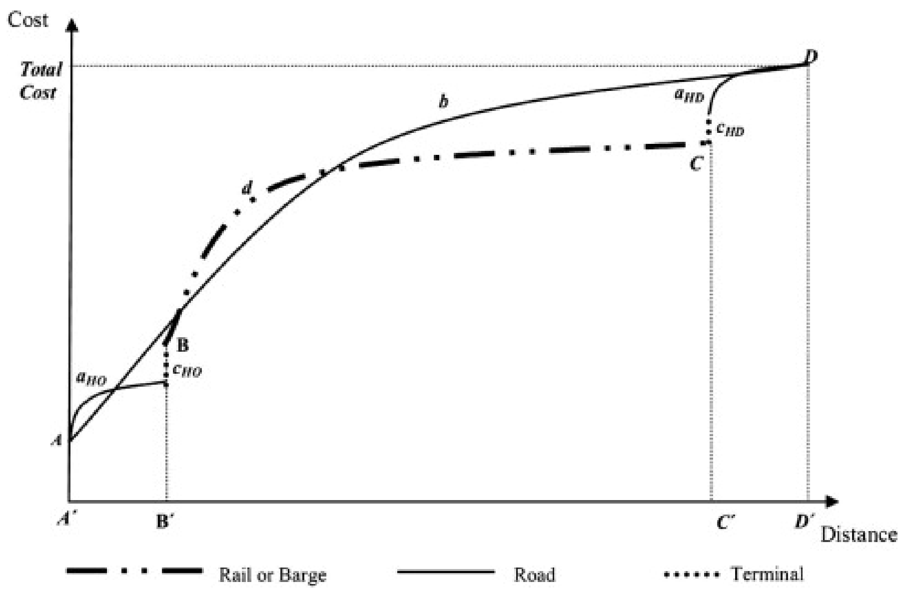


Figure 2.8: Distance dependent cost-structure comparison between intermodal system and truck-only system in the case of transport from seaports to destination. [Kim and Van Wee, 2011]

The resulting cost comparison often consists of two parts [Blauwens et al., 2010] [Button, 1993]. There is a fixed rate, which is most often expressed in €/hour, and a variable rate expressed in €/km. The fixed, time-based costs are the result of time passing by. These costs are incurred regardless of the vehicle's use. Variable, distance-related costs are superimposed on the time costs. These costs are dependent on the vehicle's use and are directly related to the distance covered. Examples of such costs include fuel, wear & tear, and damage-related costs.

Depreciation is an important element. A fairly new truck with high mileage is less desirable than a fairly new truck with low mileage. A newer truck is equally preferred ahead of an old truck. Depreciation is therefore partly time- based and partly distance-based [Blauwens et al., 2010].

What can be difficult is the comparison between alternatives. In most literature, including studies by Kim and Van Wee [2011], Macharis and Verbeke [2004], and Rutten [1995], short-distance haulage (sdh) is considered more expensive than long-distance haulage (ldh). In Van Dorsser' [1] doctoral thesis, an ldh rate of €50.36/hour is calculated compared to an sdh rate of €47.02/hour, both of which have a variable rate of €0.33/km.

The hourly rates differ due to different estimates of truck specifics and usage. The time and distance such a trip entails also plays a significant role. Short-distance haulage often occurs near urban areas, on smaller roads, and in more crowded environments. As a result, the average speed is lower. Going longer distances changes the roads used, leading to a higher average speed. Figure 2.9 illustrates how this relation between distance and average speed holds up for truck haulage.

Assuming an end-haulage of 50 km, the average speed is approximately 50 km/hour, thus requiring one hour of travel. The long-distance hauler travels, for instance, 350 km, of which the equivalent end-haulage lies between 300 and 350 km. His average speed is then 68 km/hour, taking him 44 minutes. As a result, the short haulage costs €47.02/hour * 60 min/60 min + 50 km * €0.33/km = €65.52, compared to €50.36/hour * 44 min / 60 min + 50 km * €0.33/km = €53.43. Although the hourly rate may lead to the idea that such a truck is cheaper, in practice, it is in fact more expensive due to the different operational speeds.

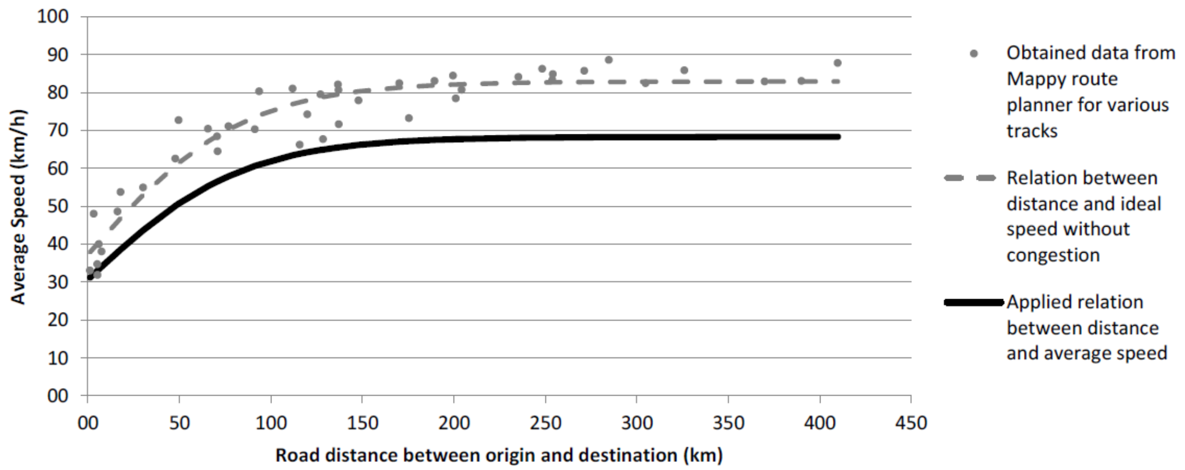


Figure 2.9: Relation between distance and average speed for a truck. [Van Dorsser, 2015]

Further considering the variables at play, Figure 2.10b demonstrates what happens if the terminal is as close to the end point as possible. In that case, the financial gap between road transport and intermodal IWT is as large as possible, creating the largest intermodal profit possible. Some end-haulage is almost always needed, but when direct discharge at the destination is possible, PPH is at its absolute minimum and the cost gap is at its maximum

On the other hand, choosing a terminal too far from the client that requires extensive end-haulage, as illustrated in Figure 2.10c, leads to more cumulative costs. This can be considered as the intermodal loss. In this case, it costs more money to ship intermodally. In practice, this is unlikely to occur and impossible to sustain.

[1]The numbers provided regarding truck haulage tariffs all have 2011 as their base year. They are here for informative purpose only. At the respective places further down this report these numbers are transformed to a 2018 estimate level. [Van Dorsser, 2015]]

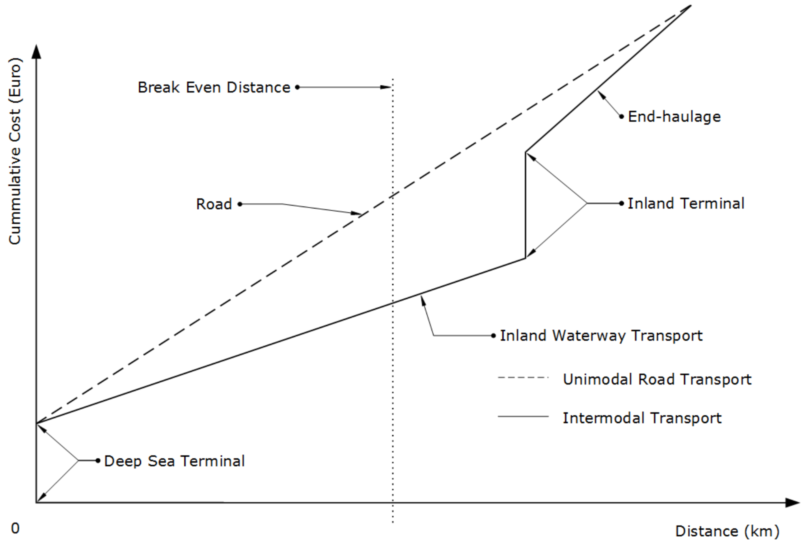
When the gap between IWT and road transport is equal to the cost at the inland terminal, the break-even distance is found (see the dotted lines in Figure 2.9). At that point, IWT has gained such a cost saving that the additional handling costs are already made up for. Since end haulage is different for every container, it is difficult to propose an overall break-even distance.

What can be calculated, however, is the correlation between the terminal handling cost, the distance share for IWT, and the end-haulage. The higher the handling cost, the less "budget" there is for end-haulage, thus shrinking the service area. Additionally, when the IWT distance increases, so does the gap between IWT and road transport, making it possible to accept more expensive handling and/or longer end-haulage, increasing the service area.

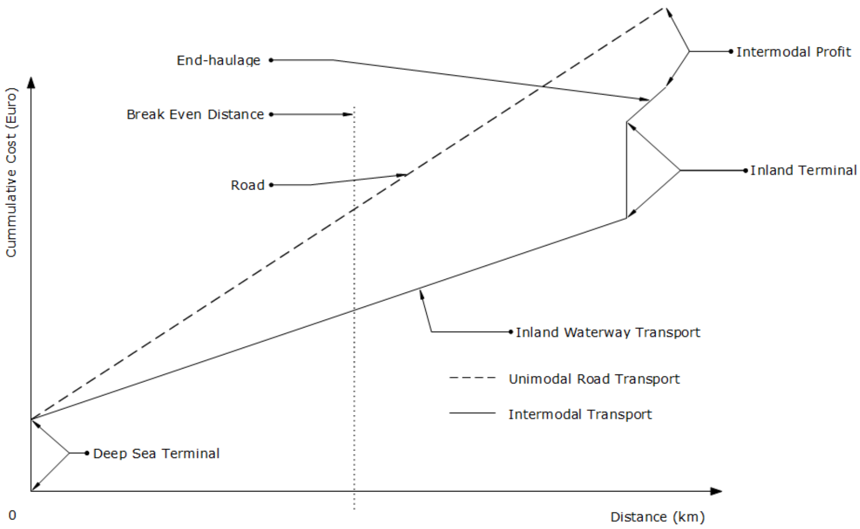
Herein lies a paradox regarding end-haulage distance, service area, and cargo volume: since the end-haulage slope or marginal cost is the steepest, it costs the most. It is therefore beneficial to reduce the end-haulage, because covering this distance with IWT is cheaper. End-haulage distance, however, defines the service area and therefore also the volume of cargo that can be served. The more containers are attracted, the greater the operability of the terminal and the ship.

Research by Kim and Van Wee has revealed the following correlation: *Specifically, to shorten the break-even distance, either reducing the rail rate or increasing the truck rate is the most effective strategy. A 1% change in these factors is almost seven times, three times, and twice as effective as a 1% change in the handling costs at terminals, rail distance, and drayage cost, respectively. [Kim and Van Wee, 2011]*

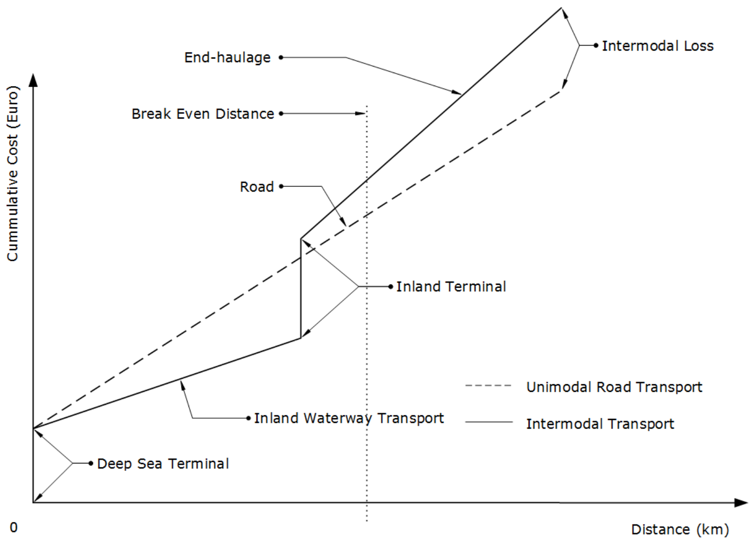
This provides significant information concerning the factors of interest. The transport costs for IWT and trucks are much times more important to the total transport costs than the handling costs, IWT distance, and end-haulage distance are. It is therefore important to be aware of the magnitude of these ratios when discussing the concepts explored later in this thesis. Reducing the handling costs at the inland terminal should not have a negative result on the IWT sailing costs, because the cost of the IWT weighs seven times heavier on the end result. Kim and Van Wee [2011] have also found that locating the terminal at the right location, leading to an efficient service area, is a major factor in the overall attractiveness of such a terminal.



(a) Overview of cost build-up over distance at break even conditions. (Modified version of the original by [Rutten, 1995])



(b) Overview of cost build-up over distance at loss conditions. (Modified version of the original by [Rutten, 1995])



(c) Overview of cost build-up over distance at profitable conditions. (Modified version of the original by [Rutten, 1995])

Figure 2.10: Impact of terminal location on cost build-up structure. [Rutten, 1995]

2.5. A Holistic Approach: The Cost-Benefit Analysis

The generalised cost approach (GCA) focuses on the individual concept's operating cost and corresponding benefits. With the concepts' holistic design intentions, it is difficult to capture all of the costs and benefits that cannot directly be charged/subtracted from the concept. An additional, even more holistic approach is therefore pursued in order to grant the concept greater impact.

Group or community welfare is a.o. influenced by large investment projects [Blauwens, 1986]. Blauwenshas therefore proposed that the best way of listing these effects is by performing a CBA. In short, investments are associated with certain costs required to make the investment in order to receive benefits from that investment. The effect on the group welfare is the result of the benefits minus the costs. If the outcome is positive because the benefits are greater than the costs, a profitable investment can be made.

The alternative for a CBA is that of a Multi-Criterion Analysis (MCA), wherein a selection of relevant criteria are analyzed together with their individual weighing factors. The main advantage of a MCA is the absence of the need to monetize all criteria [Blauwens et al., 2010]. Herein lies the risk/weakness of this approach: the outcome or result can easily be modified to achieve a desired outcome. This can be done purposely or unintentionally. Given the cost-based nature of this study, the researcher has chosen to use the CBA approach. Only factors that can be monetized are taken into consideration, and as stated by Blauwens et al. [2010], policymakers are much better informed by CBA than by a skewed summation of unweighted criteria.

By means of agreement benefits are all effects that the project adds to the community welfare by providing a product or a service [Blauwens, 1986]. By the same means, the costs are all of the effects the investment subtracts from the group welfare. If a negative benefit or a positive cost comes into play, these are left on their respective side, but with an opposite sign.

The previously mentioned split between costs and benefits is made under the assumption of a perfect economy. Such an economy, in which all facets are appropriately priced, does not exist in practice. Examples of flawed economic elements include unemployment, monetary discrepancies, and the presence of untaxed emissions (CO_2, sound, sight, etc.). Blauwens [1986] has argued that at least some of these factors can reasonably be incorporated. It may be that some effects cannot be taxed due to border crossing causes but that the community is benefiting from a solution. To do so, Blauwens has proposed the following four-level determination of whether or not to incorporate such an EC or benefit:

- There has to be an economic flaw (e.g., untaxed pollution).
- A general resolve to correct this flaw is excluded (e.g., a taxation cannot be enforced for political reasons).
- The community allows politics to correct this flaw by means of the indirect method of governmental investment (e.g., it is possible to build a ring road to divert traffic and its pollution away from the city center).
- The resulting effect should then be included in the CBA with the appropriate valuation. This is the willingness to pay of those who suffer or the willingness to pay by the government (i.e., finding an answer to what it is worth to remove or reduce the cause).

The use of a CBA is primarily convenient in cases where the community is either an unwanted or purposely included stakeholder. The application of the development of this new concept will to some extent divert road-based traffic to the more environmentally friendly alternative of IWT. Additionally, more direct transport can potentially take place, reducing the pollution caused by the detours large IWTs take. Diverting cargo away from road-based modes leads to less congestion, resulting in time gained for other road users. Trucks hauling heavy loads near urban areas also create unwanted noise and can sometimes be dangerous. All of these factors are difficult to prevent with governmental taxation, but the community is highly likely to both benefit from and be willing to contribute to a solution.

A basic CBA is the subject of the last chapter, when the concept is evaluated on a broader spectrum. It is then possible to consider whether or not it is possible to attract and whether or not public money can be used to increase success and lead to synergy effects beneficial to both the community and the individual ship and/or terminal operator(s).

2.6. Intermediate Conclusions Chapter 2

Overall growth in container volumes within the Blue Corridor is expected. Local and/or regional differences, however, are difficult to generalize and are therefore not explored. Figure 2.3 clearly indicates that in the current market, the Rhine is the primary transport axis. The majority of container flow occurs between the ARA ports and their hinterland. The strong Rhine orientation is the result of bundling cargoes in order to reap EoS via long-distance transport.

A detailed forecast of a specific operation might be valuable for a specific case, but this inevitably leads to concepts that are designed for that case. Generalizing the region in the scope of this study and therefore estimating general container throughput numbers is irrelevant for specific applications and their respective, effective throughput. Given the general increase in containerized cargo, however, it is likely that growth in annual throughput can be expected in all regions. This forecast does not, however, take into consideration strong regional impact, such as the closing of a large producer/consumer of goods.

Currently, continental container transport is fulfilled by rail, road, and water modes. Containers transported by truck can be stimulated for a mode shift when the GC of transport can be lowered . Offering a synchromodal alternative should be the goal of to-be-developed concepts [Van Riessen, 2018]. Enabling/unlocking untransported potential is another opportunity for concepts to gain market share. Current transport solutions do not appear to offer any suitable alternatives for this potential market. Attracting/unlocking these containers can therefore lead to a niche market for which there is not currently any competition.

Keeping the Blue Corridor in mind, large container vessels are already sailing on large rivers such as the Scheldt, Rhine, and Meuse, and on larger canals. Concepts focusing on smaller waterways (CEMT ≤ IV) should focus on parameters other than just EoS. For example, they should focus on the cutoff attributes [Danielis and Marcucci, 2007]. Different factors are important with respect to the mode of choice. The bottom line, however, is that it all comes down to the cost of transport. Congestion-induced delay, risk of damaged loads, being environmentally friendly, and uncertainty all can be expressed in terms of value and/or associated costs. Together, these factors add up to a total that helps to decide whether or not to choose IWT over the other modes. Knowing the value of these factors is very important for the evaluation of concepts later on.

It should not be forgotten, however, that markets and their actors do not necessarily have to behave rationally. Even when a marginally better alternative is presented, people sometimes cling to old customs. When the current service is acceptable, customers might not be willing to make a change just to potentially save a few percentage points.

Making use of the GCA enables the incorporation of most important variables. The results are therefore fair, because no strengths or weaknesses are left out. Including ECs of transport is becoming more interesting, because both awareness and policy/politics actively contribute. By comparing external costs of transport alternatives with the concept potential, external effect savings can be made tangible. Including these factors in a basic CBA will then create a potential subsidy impact. The CBA then becomes a subsidy impact measure.

Transport drivers and important parameters have now been addressed. To fulfill the current market analysis, the next three chapters each focus on a portion of the total transport network. Chapter 3 focuses on the cost characteristics of the modes of transport. Analyzing current used modes will reveal both the concept's competitors and its improvement potential. Costs associated with using containers are the subject Chapter 4. Although the container is in essence a steel box, it is important to be aware of its characteristics. The third field of study, which is explored in Chapter 5, is that of handling and terminal costs. This multi/inter/synchromodal enabler links IWT networks to truck haulage in particular. An understanding of inland terminals is required in order to be able to propose a concept that penetrates the capillaries of the Hinterland network.

3
(Cost) Characteristics of Selected Transport Modes

The previous chapter provided insight into the region of interest and transport within that region. The transport options were compared and analyzed using the generalized cost approach. Subsection 2.4.3 demonstrated the main influencing factors for the GC. This chapter focuses on the modes of interest within the applied scope. Truck transport and IWT are analyzed in this chapter in order to comprehend their respective cost levels, since these are the primary competitors for the concept(s) suggested in this thesis.

The main interest lies in improving inland waterway container transport; therefore, the first mode that is analyzed is inland shipping. The layout of that paragraph is then repeated for truck transport. Keeping the scope in mind, a small scale is of interest. For this reason, train transport is of the least interest, because it is the least likely to be included in future concepts. This part is therefore only minimally elaborated on and can be found in Appendix H.

The focus is on concept vessel(s) and terminal design. As a result, these two elements will undergo modifications in order to optimize their design and will be changed compared to their current state. Truck (and train) transport is left unchanged and is assumed to be fixed. Their analysis is therefore more compact. An overview is provided by discussing the vehicles used, the operating costs of the mode, ECs, present infrastructure, and other relevant aspects.

Section 3.1 discusses all relevant factors of the inland shipping sector. Vessels, infrastructure, and limitations are discussed. Section 3.2 then analyzes the primary competitor of IWT, which is the truck haulage market. Section 3.3 analyses the conclusions that are drawn.

Figure 3.1: The three modes under review are truck haulage, inland navigation and rail transport. [Duisport, 2018]

Cost comparisons are made on a long-term, sustainable level. The (recent) past has affected current market conditions [Al Enezy et al., 2017]. Within IWT, the excessive supply is primarily found on the major shipping corridors. The cause of this is newer and larger ships that were added in pursuit of Economies of Scale (EoS). These ships cannot sail the smaller waterways, making it impossible for ship owners to (radically) change their application. The economic recession and resulting decrease in freight volumes is often blamed for decreased results. Additionally, the current IWT sector faces shortages in crew, leading to a reduction in growth potential [Heerschop and Van Huizen, 2017].

Truck drivers are also (heavily) sought after due to the recession and the currently rebounded market [Luman, 2017]. This shortage in staff/personnel is viewed as an enabler of a potential mode shift. It is, however, difficult to quantify this into a price change, especially when having to keep price elasticities and market forecasting out of scope for truck haulage. As a result, sufficient truck capacity is assumed, excluding shortages in truck capacity. A marginal mark-up is included to internalize part of this effect.

3.1. Inland Waterway Transport

The first section analyzes existing inland navigation. Subsection 3.1.1 begins with the vessels and their classification. Their costs and cost development are the subject of Subsection 3.1.2. Subsection 3.1.3 discusses the EC of inland shipping operations for the purpose of the GC comparison. All inland vessels use a wide variety of infrastructure, as discussed in Subsection 3.1.4. The risks and reliability of inland shipping are highlighted in Subsection 3.1.5.

3.1.1. Inland Vessels: Barges, Motor Vessels, Convoys and Creep-line Coasters

All vessels designed for inland navigation of inland waterways are categorized by the Conférence Européenne des Ministers des Transports, or Conference for European Ministers of Transport (CEMT). The CEMT, held in Paris in 1954, declared an international class system for European inland waterways. The system makes use of a distinction in the dimensions of standard inland vessels. This initial classification system soon became outdated as ship designs changed. The World Association for Waterborne Transport Infrastructure (PIANC), CEMT's successor, began reviewing the classification system. After some years of debating and proposing classifications, a new classification system was adopted in 1992 [PIANC, 1990] [PIANC, 1999]. This is known as the CEMT1992 [CEMT, 1992]. The original CEMT classification dates from 1992, and as a result has become somewhat outdated. The Dutch Ministry of Infrastructure has therefore created an actualized document. Table 3.1 lists the most recent dimensions and provides insight into the classes and their corresponding vessels. These ships and their specifics are more extensively discussed in Appendix A.

Table 3.1: CEMT classifications, modified to show only motor freight vessels with current dimensions. (Translated version of Rijkswaterstaat [2017a])

CEMT class	beam (m)	length (m)	draught (m)		height above waterline (m)	cargo capacity (ton)	engine capacity (kW)	bow propeller (kW)
			laden	empty				
I	5.05	38.5	2.5	1.2	4.25	365	175	100
II	6.6	50 - 55	2.6	1.4	5.25	535 - 615	240 - 300	130
III	8.2	67 - 85	2.7	1.5	5.35	910 - 1250	490 - 640	160 - 210
IV	9.5	80 -105	3.0	1.6	5.55	1370 - 2040	750 - 1070	250
Va	11.4	110 - 135	3.5	1.8	6.40	2900 - 3735	1375 - 1750	435 - 705
VIa	17.0	135	4.0	2.0	8.75	6000	2400	1135

One clear distinction must be made regarding the normative ships and CEMT classes for the tables in Appendix A. The normative ship is the largest ship design within a specific CEMT class [Rijkswaterstaat, 2017a]. When a changed version of such a vessel is build, it might turn out that the ship no longer follows the maximum class dimensions. This can mean that it is no longer the normative ship in the old class or is upgraded to a higher class.

Referring to the subsection's title, there are many types and subdivisions of inland vessels. For this research, the concepts focus on motor freight vessels only. Barges and convoys are used far less often on smaller inland waterways than they are on large (CEMT ≥ V) waterways. For creep-line coasters, sea-to-river ships, and/or river-to-sea ships , smaller waterways are also rarely used. All of these vessel types are therefore left out from this point onward. When evaluating the final concepts, these different types will be discussed briefly in order to address the applicability of the developed technique to these vessel types. Appendix B can also be consulted for some basic information regarding these ship types.

In addition to the limitation in vessel type, the vessel size for which this research is performed is also limited. Larger inland vessels are currently also navigating in dedicated container carrier trim , such as the JOWI-class. These large carriers with capacities upwards of 200 TEUs navigate between large inland terminals such as Duisburg and the ARA ports. Their business model is not based on direct delivery to and from the client, but rather on offering long-distance container transport at the lowest possible freight rates. Linking this to the more urban purpose of the concepts, it can be concluded that these vessels are to large too penetrate the capillaries of the network. The CEMT Va (208 TEU) is selected as a current competitor. Its GCs are the subject of Chapter 6.

The lower limit is also formed based on volumes. The Péniche is so small, slow, and dedicated to its own network that it is difficult for it to attract container freight for a mode shift. Currently container transport with these vessels is also very rare, with the market not showing any further interest. The Neokemp is currently the smallest dedicated container carrier active. This vessel is therefore chosen as the lower limit. One of the primary reasons that the Péniche is uninteresting for container transport is its hold dimensions. Appendix C indicates that for these small vessels, insufficient loading results in low capacity. This effect is observable in all CEMT classes between I and IV. As a result, the dimensions of the vessels of interest are now known. Table 3.2 lists these dimensions.

Table 3.2: Dimensional limitations of the vessels of interest

	Length (m)	Beam (m)	Draught (m)
Min	63.00	7.00	-
Max	105.00	9.50	3.00

In the current IWT vessel spectrum, there are no dedicated container vessels of CEMT ≤ IV other than the Neokemp and Neokemp*. In order for inland shipping concepts to be able to compete with existing alternatives, a suboptimal "best-case" is not acceptable. Comparing the non-dedicated vessels with insufficient holds to other alternatives would lead to a skewed view. The researcher has therefore chosen to design a series of dedicated container vessels as the starting point for further concept designs. The scalable container carrier concept (SCCC) is the subject of Chapter 7. The choice to set the upper limit at CEMT ≤ IV is evaluated at the end of this study when the concepts are compared to the current solutions offered. The current solutions offered are the subject of Chapter 6.

Table 3.3: Overview of all costs between earnings and the net result. (Based on Hekkenberg [2013])

Earnings	TEU-rate * # of TEU transported	1
Operational Expenditure	Labour	2
	Fuel	3
	Repair & Maintenance	4
	Insurance	5
	Overhead	6
GC approach	Internalized external cost	7
EBITDA		8=1-(2+..+7)
Devaluation	Deprication	9
	Amortization	10
EBIT		11=8-9-10
Capital cost	Interest	12
Gross result		13=11-12
Taxation	Tax-rate	14
Net result		15=13-14

3.1.2. IWT operational costs

The goal of this research is to examine the possible future for a new inland container transport concept. The GCA was selected to research the feasibility. Based on the scalable concepts these costs are not yet known; examination of current vessel characteristics and their costs is required. Table 3.3 outlines the steps that led to the calculation of the net result. If this is positive profitability is achieved, because the earnings are higher than the sum of all costs. This subsection discusses all relevant costs that are found in inland shipping operations. The out-of-pocket (o.o.p.) costs consist of operational expenditure (OPEX), capital expenses (CAPEX), and potentially internalized ECs. The latter is the subject of the next subsection (3.1.3).

The most important distinction to begin with is the difference between accounting and cash flow. In many reports, the words depreciation, amortization, and repayment are intermingled. While depreciation (accounting loss of value of tangible assets) and amortization (accounting loss of value of intangible assets) are accounting options that are not necessarily related to cash expenses, repayment of a loan in the form of a principle payment, for example, is a cash expense. The result is that for a cost overview, repayment should be incorporated and depreciation/amortization should not. The latter categories can in turn be used for accounting purposes, eventually affecting the liable tax and thus net profit.

Beginning with the OPEX sub- factors the following distinction is made: Labour (personnel/crew), fuel (consumables), repairs & maintenance, insurance, overhead, and port charges. Together these separate costs add up to the OPEX. The next subsections will discuss each of these costs. This subsection greatly depends on the market study conducted by Van der Meulen and Van der Geest [2016]. For inland shipping, unit costs can be found rather easily. What is challenging, however, is the absence of small, dedicated container carriers. When examining these costs, it is not only the absolute number that is of interest; the development over time is also of interest. Research by Van der Meulen and Van der Geest [2016] has provided insight into the cost buildup for a variety of inland vessels. An explanation regarding the reliability of these numbers is provided in Appendix D. Van der Meulen and Van der Geest [2016] have made a distinction that the annual cost consist of four parts based on the following explanation:

The annual (nominal) cost of the goods transported in The Netherlands for inland navigation consists of four cost components; fixed, variable, personnel and other cost. The fixed cost contain depreciation, interest and insurance together with a part of repair an maintenance (50 percent of the R&M costs are deemed fixed). Variable cost contain the other 50 percent of R&M and fuel cost. Personnel cost is based on the collective labour agreement forecasts. The other costs are a collection of general business cost such as administration, communication, certificates & permits and overhead. [Van der Meulen and Van der Geest, 2016]

Their research has provided insight into the cost development from 1980 up until 2015. It is, however, important to keep in mind that these costs reflect the market average, not the costs of new entrants. Small and medium vessels especially have rarely been built during the past decade due to poor market conditions [Buck Consultants Rotterdam, 2008].

<u>2: Labour Cost</u>

The Blue Corridor is under European law. This means that IWT can make use of a European collective wage agreement (CWA). This agreement can be found in Appendix E, Table E.3, and it outlines these labor costs in more detail. Crew composition aboard inland vessels is required to follow the rules of the Central Commission for the Navigation of the Rhine (CCNR) [CCNR, 2016]. Table E.1 lists the minimum required crew depending on the sailing scheme under which the vessel operates.

Whereas the collective wage agreement contains minimum required gross wages, these do not include the entire labour cost of an employee. Apart from the gross wage insurance, employers also incur social security and other costs such as a business telephone. To accommodate these costs, a 75% mark-up is proposed. Following the market study by Van der Meulen and Van der Geest [2016], decent similarities are found. If a crew is hired via a third party, a markup of approximately 20% should be expected.

That these market averages do not necessarily hold true for all individual cases is evident given the data provided by Van Dorsser [2015]. He has proposed labor costs for a CEMT Va vessel that are 25% lower than market average based on data from his employer, Mercurius Shipping Group. As the concepts created in this thesis will have to compete with different competitors throughout the Blue Corridor, the market average is adhered.

Comparing labor costs between current small footnoteFor this vessel the researchers made the following assumptions: Vessel under consideration is the Campine barge, CEMT II. Annual distance covered = 20.362 km with 1616 hours of annual sailing. Averaging the speed at 12.6 km/hour. (base year = 2015) and medium[1] dry bulk vessels clearly reveals EoS. Whereas a small vessel can carry as much as 401–650 tonnes, a medium-sized vessel can carry 801–1,050 tonnes. This means that no extra personnel are required to carry twice the cargo. For the scalable container carrier concept, the labor cost cannot be defined as being equal for all types due to regulatory requirements. The labour cost therefore following the applicable rules. Tables 3.4 and 3.5 contain the reference values.

The annual increase of labor costs results from the CWA. In the CWA, an agreement has been made that all gross wages will increase by several percent year-on-year to correct for a.o. inflation. On smaller ships the total labor costs are substantial; therefore, the effect of this increase in significant.

Table 3.4: Cost per hour for a small dry bulk vessel over the period 2011-2015. [Van der Meulen and Van der Geest, 2016]

Per sailing hour (1616 annual sailing hours)	2011	2012	2013	2014	2015
Fixed Cost	€ 12.25	€ 12.17	€ 12.08	€ 11.71	€ 11.65
Variable Cost	€ 15.43	€ 16.46	€ 15.56	€ 15.04	€ 12.52
Personnel Cost	€ 46.54	€ 47.64	€ 48.59	€ 49.32	€ 49.73
Other Cost	€ 6.92	€ 7.09	€ 7.27	€ 7.34	€ 7.39
Total Cost per hour	€ 81.15	€ 83.37	€ 83.51	€ 83.42	€ 81.30

Table 3.5: Cost per hour for a medium dry bulk vessel over the period 2011-2015. [Van der Meulen and Van der Geest, 2016]

Per sailing hour (1702 annual sailing hours)	2011	2012	2013	2014	2015
Fixed Cost	€ 23.73	€ 23.52	€ 23.26	€ 22.42	€ 22.24
Variable Cost	€ 28.30	€ 30.28	€ 28.51	€ 27.48	€ 22.54
Personnel Cost	€ 44.19	€ 45.24	€ 46.14	€ 46.83	€ 47.22
Other Cost	€ 8.05	€ 8.25	€ 8.46	€ 8.54	€ 8.60
Total Cost per hour	€ 104.27	€ 107.29	€ 106.37	€ 105.28	€ 100.60

3: Fuel

Variable costs are mostly under the influence of bunker prices. These are directly related to the crude oil price in dollars and the appropriate exchange rate of dollar to euro. Oil has varied between $20 and $130 this century [Contargo, retrieved table for June 2018 on 03/05/2018], which underlines the volatile behavior to be expected during the concepts' life cycle. The oil price and thus the price for bunker fuel are considered variable. Whereas inland bunker fuel was approximately €350 per 1,000 liters in 2015 [Ziel, 2017], current increase in crude oil prices [Platts Bunkerworld, 2018] has resulted in a bunker price of €650+ per 1,000 liters.

The effect of varying bunker fuel prices is difficult to quantify. In many cases higher fuel prices do result in slower sailing (slow steaming) and more efficient operations since operators are pursuing cost reduction and, in some cases, even a fuel surcharge similar to the low water charge. In many cases, however, the effects cannot be fully mitigated, leading to a change in cost and eventually in margins. When a vessel is under a chartering agreement in which the charterer does pay for fuel, operations might be unaffected.

Efficient ship designs and having the correct drive train on a ship is of special interest in scenarios in which the ship owner pays for bunker fuel. As further explained in Appendix D, fuel prices can have significant effects on operations. In recent years crude oil prices were record high, leading to slow steaming. Deciding on the desired/required economic sailing speed is important for real-world applications. As seen with the NeoKemp$^{(*)}$, which is designed for high speeds (24–30 km/hour), the installed power is significant given the vessel's size. For slower than design speed navigation, the required power declines sharply due to the propeller law, which in turn leads to low engine power demand. Engines operating at low power are less efficient, however, reducing part of the effect. Although slow steaming is an option for reducing fuel consumption, designing the vessel for the right conditions can even further reduce the fuel consumption.

[1] Vessel under consideration is the Dortmund or Johan Welker vessel, CEMT IV. Annual distance covered = 22.977 km with 1702 hours of annual sailing. Averaging the speed at 13.5 km/hour. (base year = 2015)

Relevant factors influencing fuel consumption include sailed displacement, sailing speed, fouling, and waterway conditions such as depth and width [Van Dorsser, 2015]. Whereas the ship-bound parameters can be altered and optimized, waterway conditions are naturally varying and are a given. The effect of waterway interference is incorporated to prevent false conclusions in the optimization. It would be tempting to maximize the loading degree of the vessels in order to reach the most efficient operations; however, part of this effect is reduced in practice by interference with the ground, especially in shallow inland waters.

For the SCCC with optimal dimensions, an optimal drivetrain and the right operational profile are required. Advanced ship design elements are likely to be incorporated in future hulls, reducing the resistance. This will reduce the need for propulsive power and lower fuel consumption. An additional bonus of this reduced fuel consumption is a reduction in pollution, as will become clear in Subsection 3.1.3. Fuel costs will also influence the total cost, reducing the vulnerability to changing bunker prices. The specific SCCC fuel costs are discussed in Chapter 7 where fuel costs are elaborated on concerning the entire concept range.

4, 5 & 6: Repair & Maintenance, Insurance and Overhead

Repair and maintenance (R&M) are both variable and fixed. Even when a ship is idle, she will still suffer wear. When the ship is used, more parts wear, and faster wear is experienced. Beelen [2011] has not fd a direct correlation between vessels length and R&M or year of build and R&M. Combining Hekkenberg [2013] proposed formula and the calculation made by Van Dorsser [2015], two trends can be distinguished. The fixed R&M depends on the design displacement (a measure of size), and variable R&M depends on mean sailed displacement (a measure of usage intensity). The R&M can be estimated by using Formulas 3.1 and 3.2, which are the result of work by Hekkenberg [2013] and Van Dorsser [2015].

$$R\&M_{fixed} = €6.2 * Design\ Displacement + €1200 \tag{3.1}$$

$$R\&M_{variable} = €2.1 * Sailed\ Displacement + €850 \tag{3.2}$$

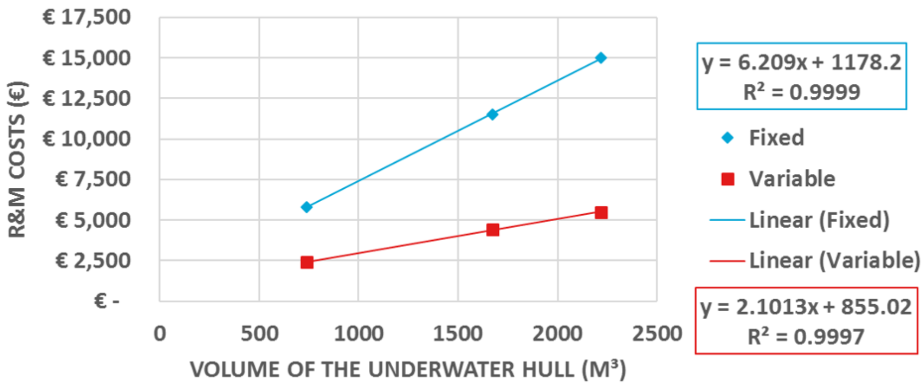


Figure 3.2: Correlation between the underwater volume of CEMT class II, III and IV vessels and their respective fixed and variable R&M costs. (Source = own work, based on Van Dorsser [2015] and Hekkenberg [2013])

Similar to the labor cost, the other costs also reflect EoS. Insurance will be slightly higher, because the vessel's value is higher in case of a larger vessel. The insurance levels are dependent on the vessel's value at that time, meaning that they decrease over time as the vessel depreciates. Hekkenberg [2013] has estimated 1.5% of the vessel's current value as a reasonable insurance cost based on work of a.o. Beelen [2011] and Via Donau [2007]. This value is also adhered this time. Given the concepts' increased complexity, their price will be higher, but a higher insurance rate is unlikely to be incurred.

The overhead is equal for virtually all inland vessels, meaning that no extra costs are incurred by the concepts compared to the standard overhead cost of existing vessels. Hekkenberg [2013] has excluded the overhead cost, since most inland vessels follow the captain/owner structure. The vessels for this thesis' concepts are unlikely to follow this structure , requiring the addition of overhead. It is assumed that the amount of overhead is linearly dependent on the amount of cargo transported. Overhead cost are therefore estimated to be 2.5% of annual earnings with a minimum of €25,000 [Van Dorsser, 2015]. The following tasks are included within the cost factor overhead: affreightment, accountancy, office expenses, and representation.

In addition to the overhead, a port charge is also incorporated. In the Port of Amsterdam (one of the ARA ports), for instance, inland vessel(s) are required to pay a port charge. As a result, a port due of €2.02 per TEU is to be expected [Port of Amsterdam, 2018]. This port due in incorporated in the SCCC model later in this thesis.

The result of increasing vessel size is now known. With the growth in dimensions, however, the reach of the vessel decreases, as the next section demonstrates. As a result, the price per cargo unit is significantly lower per kilometer in the latter case, but the ship might have to take a detour. More about this effect can be read in Subsection 3.1.4.

9, 10 & 12: Capital Costs

Capital cost or costs associated with the initial investment are only due whenever the initial loan is not fully repaid. In the current market, some vessels have repaid their investment while others are still repaying. In general, CAPEX consists of two parts. The first part is the repayment of the initial loan, often referred to as the principle. Secondly, the lender takes a risk by lending out money, so he/she demands a risk premium. Additionally, the value of money and loss of business opportunity are incorporated. In total, this adds up to the interest payment.

Financing is itself a business and can become very complex. To keep it tangible and relatively easy to work with, an annuity loan was chosen. [2] Such a loan consists of a fixed payment per period, with that period being a month, quarter, half , or full year. This payment contains both the interest and the principle. At first the remaining loan is high, which results in high interest. The result is that the principle will be low at first. As the number of payments increases step-by-step, the ship owner repays the initial loan. As the outstanding loan decreases, so does the interest due. As a result, the principles repayment share increases, leading to an increase in repayment and thus reducing the remaining unpaid loan.

The periodical payment for an annuity depends on three factors, namely the initial investment (or loan sum), the running period, and the required interest rate. A larger loan results in higher costs and/or a longer running period. The running period depends on both the lender's requirements and the type of investment. The less certain the investment proposal is, the less likely a long repayment period is to be accepted. It is important to remember that this period is something other than the depreciation period used in accounting. Finally, the interest rate depends on the risk profile and the general interest rate used by the central banks. The latter is currently extremely low, but incorporating this would lead to unrealistic proposals for future concepts, so the weighted average cost of capital (WACC) was used.

The WACC is what influences interest payments. It consists of the ratio between equity (E) and debt (D) used to finance the vessel. Both parts have their own rate of interest (R). Equation 3.1.2 shows how the WACC is calculated [Berk and DeMarzo, 2013]. The rate on equity is often between 2% and 4%, whereas the rate on debt is more like 5% to 8%. In shipping is was so that financial institutions were likely to be willing to finance up to 80% of the total sum, or even more in some cases. Banks have been lowering their positions in risky investments, especially following the crisis of 2008. This has reduced banks' willingness to finance to around 60%. As a result, ship owners have to come up with an additional 20% share in order to fill the gap. This gap can also be filled by other means of financing, such as a mezzanine, which is a loan carrying a higher risk for the lender and therefore a higher interest rate for the borrower. These more complex financial decisions and structures, however, are considered outside of the scope of this thesis. As a result, the required investment is later estimated following Hekkenberg [2013]. Given the assumed 60/40 ratio of debt versus equity and the respective rates of interest, which are 7% and 2%, the WACC would come in at 5%. This is in line with Hekkenberg's findings. Since the concept is unproven, however, it is likely to incorporate a risk markup for uncertain operational success. Two WACCs are therefore proposed: a 6% WACC in the case of a high chance of success, given this research and the likelihood a bank is willing to invest with or without the likelihood of subsidies, and an 8% rate calculated in case little is certain and the concept is subject to extreme risk and requires complex and expensive financing. The effect of changed investment levels is studied later on when performing a sensitivity analysis.

[2] An annuity is one of many financing options. The advantage of an annuity lies in its fixed periodical cost. This however means that in the first year little of the loan is actually repaid and primarily interest is paid. Choosing a linear repayment schedule will result in quicker repayment of the initial loan but will demand (very) high payments during the first years of repayment. For the concept this is highly likely to lead to cash flow problems as the revenue stream is also starting during this period. The gap between revenue and expenses is than maximized and unbearable.

$$WACC = \frac{D}{D+E} * R_D + \frac{E}{D+E} * R_E \tag{3.3}$$

As previously mentioned, accounting purposes allow for depreciation. For standard inland ships, depreciation periods are often considered to last 20–35 years. Special cases will, however, see different depreciation schemes being adopted, but again, these are accounting moves, not cash expenses. Accounting depreciation/amortization can in turn be used to decrease the EBIT so that less tax is due. The accounting lifetime is itself separated from the economic lifetime, because in practice the vessel's lifetime is generally longer [Hekkenberg, 2013] [Beelen, 2011]. This study uses 25 years of depreciation, after which the residual value of the vessel is estimated to be 25%; therefore, an annual depreciation of 3% per annum is assumed. The initial value of the ship, especially with the concepts' use in mind, is attributed in the chapter 7 specifically dedicated to the Scalable Container Carrier Concept (SCCC).

3.1.3. External Costs

Chapters 1 and 2 explained the choice to incorporate external effects. These effects are monetized in order to be able to be included in the calculations. The valuation of an external effect is not a conclusive number that holds true under all conditions. In practice, the value depends on many factors such as awareness, income, policy, etc. Exhaust gases emitted near an urban area, for instance, are considered more undesirable than those emitted in a rural environment. At the same time, there is a difference between the stated and revealed preference from the general public [Button, 1993]. The willingness to pay (WTP) often differs from the willingness to accept (WTA) [DG MOVE, 2014]. Altogether, this makes the unanimous valuation of external factors impossible. As a result, many researchers have investigated these costs in order to find an acceptable valuation method and corresponding values.

Based on a study focusing on Dutch external cost Figure 3.3 illustrates the marginal ECs of IWT according to Schroten et al. [2014]. When concluding anything based on this figure, bear in mind that the results are IWT averaged, rather than being for a specific ship with a specific operational profile. Monetarily, the main contributor appears to be air pollution, independent of the scenario. Accidents significant enough to cause ECs did not occur in either case.

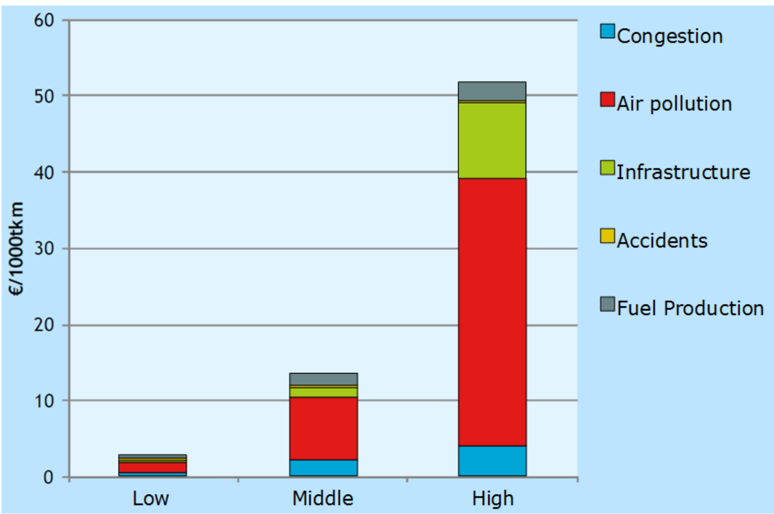


Figure 3.3: External cost of average IWT under three different scenario's. (base year = 2010) [Schroten et al., 2014]

Currently very limited internalization of ECs is common practice. The reason for this absence has many causes, all of which come down to the problem of putting the right price on these unwanted external effects. The external costs that are most likely to be internalized are air pollution and congestion. In this case, "internalized" refers to the likelihood that a regulating body appoints the external effect to the cause of that effect. A truck emitting CO_2 will then face a charge/tax for emitting that pollution. Policy/politics have not come to a general consensus to value these costs, for instance, throughout the EU. In an effort to generalize the variety of external effects for IWT, the costs of pollution make up approximately 60% of the total estimated ECs [Schroten et al., 2014].

DG MOVE [2014] did a very large study on updating the European handbook on ECs of transport. Their report was written to serve as a basis for future calculations of user charges within the EU. The problem with many newer sources is that they rely heavily on previously determined numbers and research. The study by DG MOVE [2014] was conducted in close cooperation with Professor Werner Rothengatter from IWW Karlsruhe and Professor Chris Nash from ITS Leeds. Both are well known and respected experts in the field of transport economics with long-term experience in EC calculation. Since their study has been conducted with the help of many experts in the field of EC valuation, the region of interest together with the richness in data make this source the backbone of EC valuation for this report. Appendix F lists their original data for the year 2010 and updated 2018 values. The relevant values for IWT are provided in Table 3.6. Be aware of the different units per externality.

Table 3.6: Updated external costs for IWT and base year 2018.

External Cost	3. Air Pollution	5. Climate Change	6. Well-to-tank
Unit measure	€/1000tkm	€ct/l MDO	€ct/vkm
Value	1.3	34.6	1.1

3.1.4. Infrastructure; Waterways

The dimensions currently chosen as CEMT standards for ships are interrelated with the infrastructure for which they are designed. As the next Part will discuss in greater detail, the infrastructure of inland waterways – namely rivers, canals, and inland lakes – is to a large extent managed. Fluctuations in experienced discharge, which is the measure for water flow, are caused by seasonal fluctuations in weather. These changes have, however, always been present, leading to significant but expected impact on the market. “Low Water Surcharges” compensate ship owners for the suboptimal loading conditions at times of low water [Contargo, 2017]. Unexpected/extreme cases still have significant impact on the market and related pricing. Rivers and especially canals and lakes have a largely regulated water level due to the help of locks. The concepts will not be tested for seasonal changes in water levels in order to limit the amount of variables. This type of effect is discussed when performing the sensitivity analysis.

These locks enable more controlled navigation but at the same time determine the maximum vessel size. The first standard dimensions of 38.5m by 5.05m were set by the French Minister of Infrastructure Charles de Freycinat. When de Freycinat came up with a law for the improvement and additional digging of canals in 1879, the Péniche (Spits) became the normative ship for those canals [Rijkswaterstaat, 2017a], which meant that the Péniche was the maximum size of vessel that had to be able to easily and swiftly navigate those canals. Today, all relevant waterways and corresponding vessels are labeled with a CEMT class distinction.

These normative ships are currently very useful, because they make distinction and mutualization possible. Decisions regarding the normative ship are primarily based on horizontal dimensions, for which the width or breadth has the most impact. The sluice chamber is often longer than one ship length, making the length less important. Altering loading conditions can alter the draught and air draught.

For example, Figure G.2 in Appendix G provides an overview of the locks in the Netherlands. These locks control the water depth across the river, tame the currents to some extent, and connect waterways of several types with each other. As mentioned in the CEMT classes for ships, these locks are one of the limiters to the maximum size of ships able to navigate across these waterways. Reducing the limitations by increasing locks is costly, and in practice, it takes a great deal of time. This means that locks and their dimensions can be considered to be a fixed limit for the scope of this research. No real sluice improvement strategy is in place for the next decade, meaning that no significant change in CEMT class is expected. The same applies to Belgian and German waters. Figure G.2 reveals the number of locks that control the network of waterways in the Netherlands.

In the Rhine delta, ship sizes and lock limitations are currently closely interrelated because major traffic lines normally have larger vessels sailing on them, requiring large locks. On the other hand, canals that experience less cargo transport are usually sailed with smaller vessels. Close interrelation is one reason for this reality. Only small vessels can sail on these smaller waterways, and these vessels can carry less cargo, minimizing the EoS and leading to a more expensive operation. With the costs being higher than should be the cargo stream will decrease, potentially starting a vicious circle stopping transport in time. This close interrelation is also evident in the labeling of inland waterways. As Figure 3.4 indicates, all significant rivers, canals, and waterways across lakes are marked across the delta. [3] More specific figures for each of the three individual countries can be found in Appendix G.

The major difference from other land-bound transportation modes is the natural presence of the majority of this infrastructure. The rivers are created by nature, while people dug most of the canals of significant size at least a century ago. In the Netherlands, which is situated in the middle of the Rhine delta, a fine-meshed network of inland waterways is now present. The existence of this network with abundant capacity has a welcome extra. Increased use of these waterways does not require expensive investments in increasing the capacity of the total cargo transported. Table 3.7 provides an overview of the length of small waterways.

Table 3.7: Length of waterway network CEMT Class ≤ IV. [Buck Consultants Rotterdam, 2008]

Country	Length of waterways classed ≤ IV	% share of total waterway length
Belgium	1116 kilometers	72 %
Germany	3112 kilometers	49 %
France	6571 kilometers	78 %
The Netherlands	3255 kilometers	65 %
Total	14054 kilometers	66 %

These smaller waterways comprising up to two thirds of the total waterway network within the Blue Corridor are not necessarily valuable for inland waterway transport. Figure 2.3 clearly indicates that at present, all major transport volumes follow the main waterways. Close to the main transport flows of over 100 million tonnes (the trunk), there are several “branches” with lesser annual transported weights. Many of these smaller branches are of interest in relations to the concepts introduced in this thesis. Research conducted by Van Staalduinen [2014], for example, was performed for the sake of investigating regional container transport. Based on research such as this, the waterway network in the “Noord-Holland” province should be upgraded by selecting promising waterways only [Van der Geest et al., 2018].

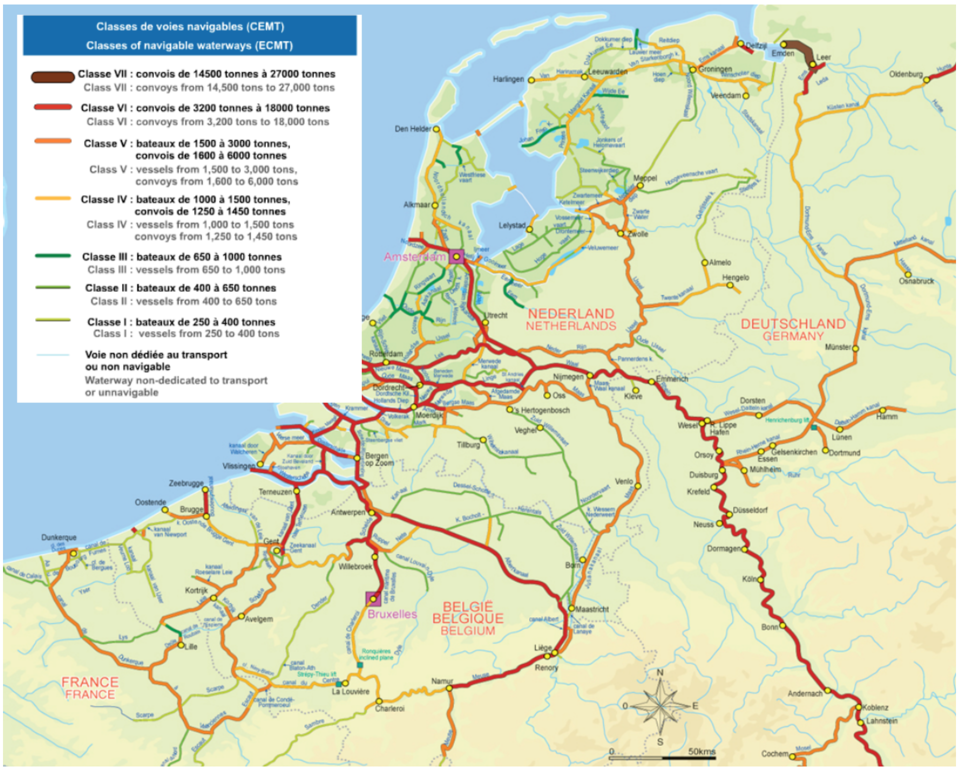


Figure 3.4: CEMT class inland waterways in Belgium, The Netherlands and Western Germany. [Buck Consultants Rotterdam, 2008]

[3] Although the source [Buck Consultants Rotterdam, 2008] dates ten years back, no significant changes have taken place in the last decade. Minor changes such as the opening of a small canal near Den Bosch, The Netherlands are negligible for the overall impression provided by the image. Currently no maps or info-graphics for CEMT classed waterways with the same level of detail are available.

Draught and Airdraught

Apart from the width and breadth limitations, draught is in many cases the limiting factor for inland vessels. Given the length and bread of a vessel, its draught is the result of the loading conditions. Smaller waterways especially often have limited depths, leading to devaluation of the waterway's CEMT class. Containers being relatively low in density often leads to a limited draught of inland vessels carrying them. Currently, vessels receive their classification based on their maximum sailing dimensions, of which maximum draught is one. Classifying the concept potential at a lower (or more shallow) maximum draught might increase its sailing reach. Air draught is directly connected to draught. Everything that is not underwater has to be above it, and in the case of inland container carriers, there are limitations in this area. Accidents occurring due to a vessel's air draught surpassing the underpass height of a bridge are common.

Figure 3.6a provides an example of an inland container vessel that can only just pass under a bridge. In the case of inland shipping, advanced ship designs, improved cargo loading, and container developments have provided the sector with the ability to transport higher loads. This is discussed further in Chapter 4.

Man-made river crossings in the form of locks and bridges have put limitations on the inland waterway network. New ships with potentially different designs have to cope with the existing limitations on infrastructure, because changing or reducing these limitations is often costly and takes many years.

The tables in Appendix A provide the length, beam, and draught of several ship types. The minimum height listed in the last column is dependent on the cargo conditions. Containers can be stacked aboard, leading to a variable cargo height depending on the loading conditions. Many inland container vessels are equipped with retractable wheelhouses, enabling the vessel to reduce its maximum air draught for a short period while passing overhead obstacles. Figure 3.5 shows the MV Camaro transporting containers while also having several barges alongside and in front of it. The wheelhouse is mounted on a movable, retractable column. During navigating, the wheelhouse is up, allowing for maximum visibility. This is also legally required. When such a vessel has to pass a bridge with an air draught limitation that is below the height of the wheelhouse, the wheelhouse may be temporarily lowered. During normal operations, the maximum blind spot distance for the wheels-men is set at 250 meters [CESNI, 2015]; however, this is specifically the case for half loading without ballast conditions. It can be imagined that these kinds of rules are always up for discussion during ship design.

Figure 3.5: MV Camaro (CEMT Va) pushing a container barge (CEMT E II) while also having two barges alongside it (CEMT E II in a long version and an E II in short edition.) [found on MarineTraffic.com, year = unknown]

Research regarding the total vessel height for container vessels was conducted in 2015 on Dutch inland waterways [Brolsma, 2013]. The research was conducted due to the occurrence of accidents where vessels with container stack heights greater than bridges' air draughts damaged bridges with their top rows of containers. Figure 3.6b shows an example of such an accident. The Dutch Ministry of Infrastructure demanded that Brolsma [2013] would perform measurements of experienced container stack height and experienced air draughts. The CEMT classification for air draughts dates from a period in which standard containers of standard height were the standard.

When this report came out in 2013, the higher containers, referred to as High-Cubes (HCs), had become a far more common container type. This increase has led to an increase in the stack height of containers. Container specifications are discussed in Chapter 4. The result of carrying HC containers was that vessels loaded with 3 respectively 4 layers saw their air draughts increase by approximately a meter.

Another important result from this study lies in the ballasting possibilities and the usage of ballast water. The variety in ballasting capabilities and utilization of these capabilities was extreme. At one of the measurement locations, researchers contacted the passing ships with questions regarding their ballast usage and discovered the following:

"Of the 188 passing container vessels, providing us with a complete answer, 89% had the possibility of taking in ballast water (1996 was 68%) with on average a volume of 370 m^3 (1996 had no average provided, majority between 50 and 200 m^3). The ballasting capabilities ranging from as little as 20 cubic metres up to 1200 m^3. Remarkably, 84% of ballast capable respondent told that they did not have any ballast on board at that time. On average 140 m^3 (= 140 tons), ranging between 15 and 500 m^3 were taken in at that time for those that had taken in ballast water." [Brolsma, 2013]

Ballast use in inland shipping is rare. Ballast is primarily used for trimming applications to counteract container weight differences. More specifically, it is used to lower the aft of the ship in order to fully submerge the propeller. Stability generation is a secondary application of ballast systems. For example, a Neokemp* with a third layer of empty containers requires additional ballast. Combining this knowledge with the results that, on average, the respondents can take in 370 m^3 of ballast (note that these ships are likely of average or slightly above-average Rhine-Herne size), these ships can alter their air draught by approximately 50 centimeters. This is therefore only a marginal change when compared to the ship's dimensions and the effect of one or two HC containers.

Taking in ballast to reduce the air draught is not free, however. Taking in ballast deliberately makes the ship heavier, resulting in increased draught. The two primary downsides are increased resistance caused by a larger underwater body and less ground clearance.

The latter seriously limits operations, because grounding and/or damage to the keel are real dangers. When the resulting height under the keel is insufficient, less cargo can be taken on, reducing the effective payload for the operation [Covadem, consulted on 18/02/2018]. Resistance will also increase when the keel is close to the ground. The underside of an inland ship is not perfectly flat. The propeller(s), rudder(s), and any additional appendages are fragile, making them vulnerable to damage due to grounding. The danger of damaging these essential propulsive parts requires a safety margin with respect to bottom clearance.

(a) MV Ricardus passing a low bridge. [Bureau voorlichting Binnenvaart, year = unknown]

(b) Collision with the bridge 'Burgumerdaam' on the Dutch canal 'Prinses Margiet'. The vessel involved was the CEMT Va class 'Fides' carrying 114 empty containers. [De Boer, 2011] [Brolsma, 2013]

3.1.5. Infrastructure; Congestion and Blockage

Accidents taking place in every mode of transport. These not only hinder the vessel(s) present in the accident, but they can cause problems for a large part of the network. Precautions have been made to reduce the risks of, for instance, the blockage of waterways. The maximum monohull vessel length is set at 135 by the Central Commission for the Navigation of the Rhine (CCNR) (Article 11.01) CCR [2015]. For this study, these limitations do not play a role in putting a boundary on the maximum vessel size.

When navigating in inland shipping, congestion is minimal compared to in other transport modes. The waterways themselves have abundant capacity [Port of Rotterdam, retrieved 15/02/2018], but they are limited at the locks and bridges. The waiting time at these points is likely to increase with the number of passing ships. Luckily, the addition of this thesis' concept would be insignificant compared to the total amount of inland freight vessels. Additionally, the concept focuses on small waterways where there is less likelihood of congestion and significant increases in waiting times. It is assumed that congestion at bridges and locks will be no different than it is now. At present, the Dutch Ministry for Infrastructure and Water Management is looking into potential hotspots between now and 2040, so that bottlenecks can be prevented and/or reduced.

Congestion is, however, caused by waiting times in deep-sea terminals. Significant increases in waiting times have occurred in both Rotterdam and Antwerp to such an extent that it has been discussed in the news. The Port of Rotterdam has acknowledged this problem and is working hard to reduce both waiting times and the frequency of “above average waiting time” occurrence [Dijkhuizen, 2017a]. The cause of the congestion is in part the unexpected growth in cargo volume. In the first half of 2017, for example, the port saw an increase of more than 10% in handled containers.

Waiting time is not typically an issue for smaller inland terminals. Larger inland terminals such as Duisburg are strongly managed and less complex; therefore, waiting time here also neglected. Waiting times in the ARA ports are estimated to be 12 hours in the standard scenario. There are reports of even more extreme cases of multiple-day waiting times, yet this is unlikely to remain [Dijkhuizen, 2017b].

One of the more rare forms of congestion is that of blockage of the waterways. When a vessel sinks, loses cargo, or comes into contact with another vessel or infrastructure, it affects the waterway. Whereas highways exist every couple of kilometers with a secondary network adjacent to the main highway, inland shipping does not typically have such a structure. In the winter of 2016, for example, a vessel came into contact with water level-regulating infrastructure near Grave (The Netherlands). As a result, the river Meuse was blocked from 29 December, 2016 until 24 January, 2017 [Rijkswaterstaat, 2017b], leading to an additional sailing time of up to 28 hours for CEMT III and larger vessels. Severe blockage of waterways is not common; however, when it occurs it often remains present for a long period and has severe effects. In the case of this event during the first quarter of 2017, cargo volumes for both construction materials and containers fell short of forecasted values [Van der Meulen et al., 2018]. These types of problems are not included , however, because the occurrence interval is very low and the smaller ships are likely to have the choice of another route. While large vessels cannot navigate smaller waterways, smaller vessels can use larger waterways if a detour is required. More assumptions for the concept alternative are described in Chapter 9.

3.2. Road Transport

The second transport mode that is of interest is transport across roads. Relevant road transport is container haulage by truck. These vehicles can be categorized into two distinctive types. Some have a fixed container bed (see the top left example in Figure 3.7) and are often referred to as truck, while others consist of a truck & trailer. The latter is most frequently used and is therefore chosen as the competitor of IWT for the purposes of this study. Such truck and trailer combinations are also referred to as articulated vehicles, meaning that they are vehicles with (semi-)permanent pivot points to allow for increased manoeuvrability. The primary advantage of these trucks is the ability to separate the trailer from the truck. As a result, the trailer can be decoupled quickly so that no immediate handling of the container is required before the truck can leave.

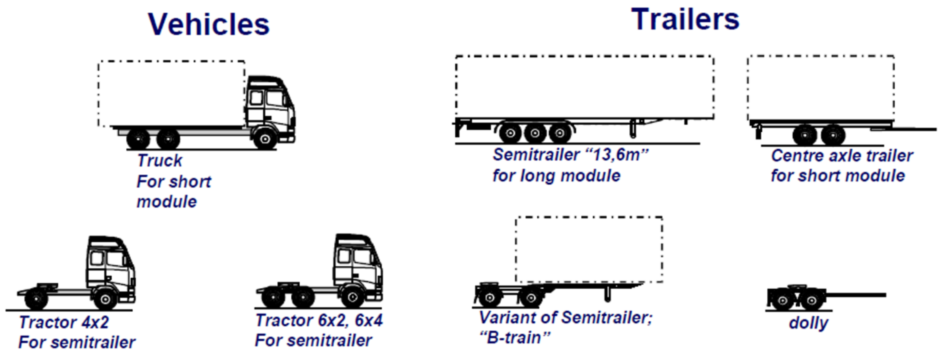


Figure 3.7: Terminology for vehicles and trailers used in trucking. [Larsson, 2009]

Truck haulage appears in several forms. There is short-distance travel used for regional transport. Long distance haulage is used for interregional and international cargo movement. The transportation of loaded trailers on trains is a special case used to reap EoS on very long-distance transport or in the case of natural boundaries such as the North Sea, the Baltic Sea, and the Alps. For example, the United Kingdom (UK) is connected to the European continent with help of ferry operations, where trucks can pick the trailers up by trucks at the port of arrival. Around the Alps, sometimes they also get transported on the train in order to cross the mountains. This is then referred to as a rolling highway. Both of these applications are deemed outside of the scope of this thesis, meaning that the concepts should strive for a mode shift of these containers. The possibility of transporting loaded trailers as a whole is not, however, the intended future application of the concept.

3.2.1. Truck Haulage

Figure 3.7 provides an indication of the vehicles used in truck haulage. Of the applicable rules and regulations, Road Class 2 is of primary interest. Figure 3.8 shows how road vehicles are classified. The aforementioned second class can pull either one large semi-trailer or a combination of a truck and trailer, translating to one 40-foot or 45-foot container or two 20-foot containers. Road Class 3 has the largest cargo-carrying capacity, since a total of three 20-foot containers may be loaded. This class was the last added in an attempt to solve congestion-related problems. Whether or not this latest class, also known as the long heavy vehicle (LHV), is a threat to IWT remains to be seen. Due to regulations, the application of LHVs is limited. Similar to inland vessels, many LHVs cannot make use of all roads. A German study allegedly reported that IWT was not negatively influenced by the introduction of the LHV [BAST, 2016], but the effect of further adoption of LHVs on the market should be studied in the future.

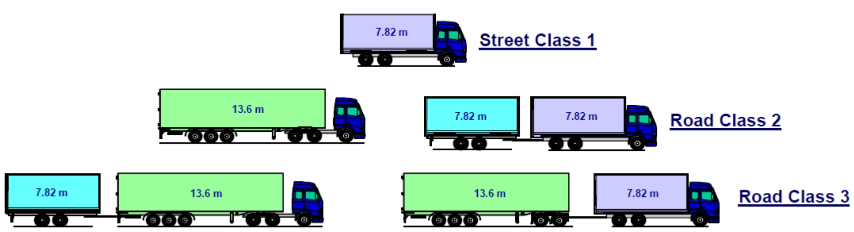


Figure 3.8: EMS road classes and corresponding maximum truck size. [Larsson, 2009]

Congestion on roads is both caused and experienced by the trucking industry. As the class names already indicate, the higher the class, the larger the vehicles and corresponding infrastructure are. Before the infrastructure is discussed, the impacts of different vehicles sizes are explored. Figure 3.9 illustrates how many vehicles have to be used in order to transport the same load. Adding Road Class 3 has resulted – in comparison with Road Class 2 – in a reduction of one entire truck for the transport of the same load, up to a maximum reduction of 33% of vehicles. As a result, the same amount of cargo is hauled while taking less space on the road and reducing fuel costs. In practice, only a few LHVs are used, because they are still in the introduction phase, which means that a set of rules limits their current use. For high-frequency, easy-to-reach hubs, these exemptions for LHVs is potentially interesting. In the case of low-frequency, difficult-to- reach places, the LHV exemptions are currently is not.

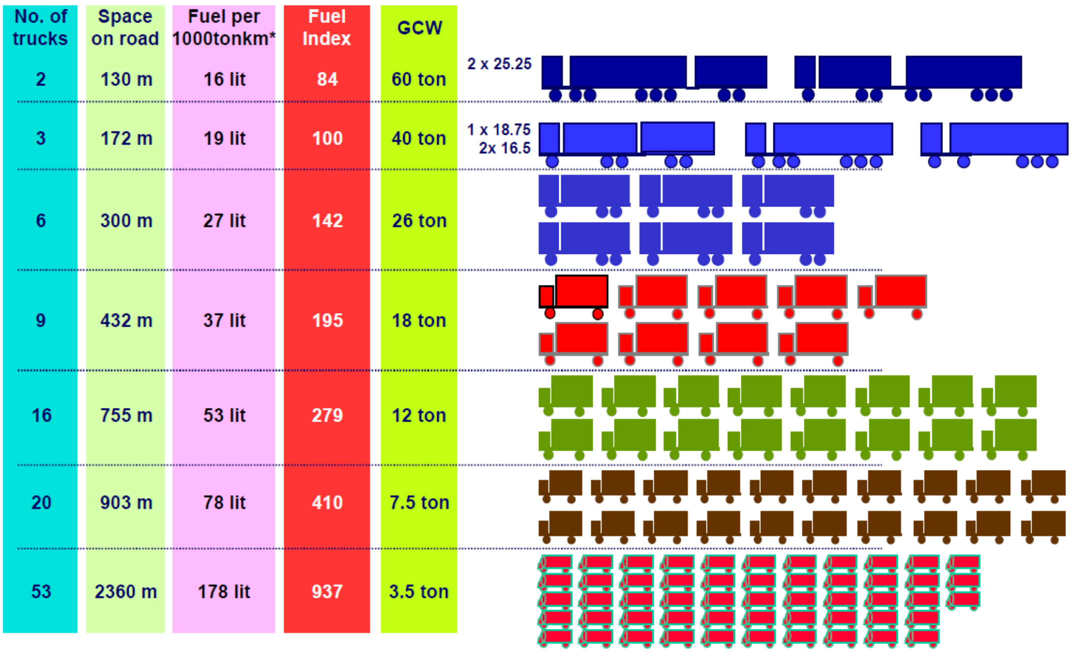


Figure 3.9: Impact of different vehicle sizes to transport 106 EU pallets with 600 kg/pallet (EU pallet = 800*1200mm). [Larsson, 2009]

3.2.2. Truck Haulage Operational Costs

Cost structure-wise, truck owners often use an hour and kilometer-based tariff to calculate the fixed and variable cost buildup. For every hour regardless of use the truck depreciates and requires maintenance, the driver requires a salary, and overhead applies. When the truck is moving fuel is consumed, potential toll/road tax has to be paid, and additional R&M have to be carried out for wear & tear.

Multiple researchers have attempted to quantify these costs. Van Dorsser [2015], Panteia [2004], Macharis and Verbeke [2004], Van der Maaten [2002], Ziel [2017] and Konings [2009] have all investigated road haulage costs. They have based their costs on both the annual distance and the annual time these trucks are operated. There is little consensus concerning what is right, however, leading to a first cause for different numbers.

For example, Van Dorsser [2015] has proposed an hourly rate of €50.36 and a kilometer rate of €0.33. Based on Panteia [2004] data, his own previous work, and work conducted by Grosso [2011], Van Dorsser has assumed 130,000 annual kilometers and 2,500 operational hours. Looking into one of his sources, namely the report completed by Panteia, reveals other assumptions and numbers. There is a difference between Van Dorsser's and Panteia's data for 2010.

Panteia [2004] has based his/her calculations on 135,000 km and 2,600 hours, resulting in an average operational speed of 51.923 km/hour. For the year 2010, Panteia found a market average of €66.63. Using Panteia's speed with Van Dorsser's numbers leads to the following calculation: €50.36 + €0.33 * 51.923 = €67.49. This means an absolute difference of €0.86 per hour, under different assumptions. Altering the model used by Van Dorsser to the same conditions used by Panteia decreases the hour costs to €49.39 (base year = 2010), making the estimated number virtually equal to the market average.

Extrapolating these assumptions, numbers, and considerations into a feasible, realistic cost estimation for long-haul trucking leads to the following numbers: regardless of its loading condition, on average a truck has a fixed hour cost of €50.00 (2010). The variable cost primarily depends on fuel consumption, which depends on the loading conditions.

When loaded, a truck uses approximately 75% more fuel, since the required power can differ by 75% [Smokers and Rozendaal, 1998]. The €0.33 per kilometer is for loaded conditions. Following the 75% difference, empty runs come in at €0.20 per kilometer. In practice, the fuel usage differs depending on whether a TEU of FEU container is transported. Additionally, the placement of the TEU on the trailer plays a role. These effects are left out, however, and as a result, the average €0.33 cents per kilometer of variable costs is used.

The introduction of this chapter mentioned that trucking faces a shortage of drivers [Luman, 2017]. As a result, prices are increasing. It is therefore assumed that the fixed 2018 price will increase by 5% per hour. This markup is reflected in the 2018* column.

Short-distance truck transport, often referred to as pre-haulage and end haulage, does not follow the same figures as long-distance truck transport. Van Dorsser [2015] has provided an hourly rate of €47.02 (€3.34 less than the long-distance travel, base year = 2010). Translating this difference to the unimodal assumption of €50.00 leads to the rounded figure of €46.50 (2010).

All of these numbers have been calculated for the base year 2010. Using Panteia [2004] research to translate them to 2018 levels provides the following assumed values.[4] For short haulage, the same 5% markup for driver shortages is applied. Section refsubsec:GCoutcome explained this subject in more detail.

Table 3.8: Truck haulage assumed values. (Result of own estimations based on Van Dorsser [2015], Panteia [2004] and Luman [2017])

Loading Condition		Hour Rate			Kilometer rate	
		2010	2018	2018*	2010	2018
Long Distance	Empty	€ 50.00	€ 55.00	€57.75	€ 0.20	€ 0.20
	Loaded	€ 50.00	€ 55.00	€57.75	€ 0.33	€ 0.33
Short Distance	Empty	€ 46.50	€ 51.00	€53.50	€ 0.25	€ 0.25
	Loaded	€ 46.50	€ 51.00	€53.50	€ 0.40	€ 0.40

3.2.3. External Costs

The ECs for truck haulage are determined using an approach similar to that used in Subsection 3.1.3. In contrast with IWT, transport by truck ticks all the boxes in terms of EC factors. Appendix F explains more with respect to the determination of the exact values. Again, the values as based on the work of DG MOVE [2014].

The occurrence of external effects that cannot be or are very difficult to internalize, such as accidents and noise costs, is relevant to truck haulage. As Table F.1 indicates, congestion, air pollution, climate change, and well-to-tank ECs can be internalized, which means that transport by truck affects the environment in seven different ways. Each of these distinctive external factors can be monetized, making them ECs. Some of the ECs are results of a broader total, as is the case with noise. For example, when two trucks ride at the same location at the same time, a longer and louder sound is produced, but neither individual can be blamed for this effect.

Current policy/politics focuses more on the “polluter pays” principle, according to which the individual is charged for causing externalities. *Ceteris paribus*, when policy/politics arrives at the point where they implement this principle by internalizing the ECs, all transport will become more expensive.

If the to-be-developed concept could reroute transport flow and thereby reduce the number of truck moves, the “gain” or benefit would be a reduction in ECs. How large this reduction would be depends on the number of trucks/weight, the distance travelled, and the location in which the original transport took place.

[4] In between 2010 = 120.93 and 2015 = 131.45 the total costs on average rose with 8.6 percent. Extrapolating requires some insight in the numbers. During 2015 the price level was lower than it was in 2014, meaning no increase has to be deemed certain per sé. As a result the assumption was made that prices rose 10 percent compared to 2010.

Table 3.9: Updated external costs for IWT and base year 2018.

	External cost	Loaded HGV		Empty HGV		Unit measure
		Urban	Motorway	Urban	Motorway	
1.	Congestion	228.7	162.3	228.7	162.3	€ct/vkm
2.	Accidents	1.4	1.5	1.4	1.5	€ct/vkm
3.	Air pollution	2.7	0.6	2.5	0.4	€ct/vkm
4.	Noise	175.8	10.9	87.9	5.4	€/1000vkm
5.	Climate Change	14.2	8.5	6.7	4.7	€ct/vkm
6.	Well-to-tank	6.2	3.7	1.5	1.4	€ct/vkm
7.	Infrastructure	-	-	-	-	-

3.2.4. Infrastructure; Roads

All previously discussed combinations vary in length, but there are no trucks that carry two containers next to each other or perform stacked container transport. The reason behind the lack of such trucks lies in the infrastructure. Road transport takes place on roads. To prevent or minimize damage to the road, there are weight limits in place for trucks. The total weights of the vehicles may not surpass the gross combination weight (GCW) [Freights.EU, 2014]. Gross combination weight restrictions are set by the road-owning parties, which in most cases is the ministry of transport.

Whereas the inland waterway network could be defined as a tree network with some additional meshing, the roads across the region of interest are extremely finely meshed. For all vehicles except those in Road Class 3, all normal roads are accessible and may be used. Road Class 3 and in some cases Road Class 2 vehicles are not allowed near urban areas other than industrial sites. In the future, however, it is possible that some of these limitations will be lifted. Policy/politics in search of emission-reducing strategies are also researching the effect of allowing more LHVs.

3.3. Intermediate Conclusions Chapter 3

Comparing the two modes under review is best performed when using the GCA. Significant differences in ECs exist between the modes and can be externalized. While truck (and train transport) is deemed given and therefore fixed in their configuration, IWT is made up of different vessels with different cost structures. As a result, Chapter 7 develops a dedicated scalable container carrier concept (SCCC) in which all IWT costs are calculated in order to achieve a level playing field and be able to compare the options on equal terms.

In terms of infrastructure, roads were the only type with congestion-based ECs. These costs were significant, resulting in a great opportunity for IWT to provide a mutual gain. Truck owners can reduce their current need for drivers and reduce the costs they experience due to congestion. The community can benefit from less external effects such as pollution, noise, congestion, and accidents. All of this can potentially be achieved by implementing a container service across water.

Intermediate Conclusions: Inland Waterway Transport

Inland waterway transport can create EoS by increasing the vessels' size and corresponding carrying capacity. The size of the vessel does, however, automatically limit its use and thereby the market segment it can reach. As a result, there is a certain optimum size at which the EoS are maximized compared to the revenue the vessel can still generate for a specific niche market. Since no fixed case is studied in this thesis, the potential is not fixed. In Chapter 7, a scalable container carrier concept is designed for the purpose of finding optimal dimensions in order to find the most profitable ship for multiple scenarios.

The different cost factors have been either explained and left open for Chapter 7 or have been determined in this section. One of the more typical results is the internalization of ECs and the extent to which this is considered achievable. For IWT is resulted in the expected possible internalization of exhaust gas emissions only. Being approximately 60 percent of the total ECs, the total external effects are used in the CBA. Future scenarios can be checked by taking the internalization of ECs into consideration.

In terms of the design aspect of the SCCC, the concepts should especially keep draught and air draught in mind. Adequate use of ballast is rare in inland container shipping. The concepts to be developed should put more effort into using ballast as a capacity-maximizing variable. Taking in ballast can either ensure sufficient draught in empty conditions, increase the stability to allow additional stacking height, or decrease the air draught. Using the minimal amount of required ballast, on the other hand, can increase the draught under the keel, which lowers the resistance and can reduce the fuel consumption. This is directly related to the revenue and costs that together form the basis of the profit navigation can potentially produce.

Intermediate Conclusions: Truck Haulage

For the purposes of this study, the current truck haulage business is assumed to be fixed. Chapter 12 will reflect on this assumption further. The result of this assumption is that known vehicles with known costs can be used. Differences between short and long-distance haulage is reflected in costs. The trucks of interest are the articulated vehicles that are currently by far the most used and preferred by the sector/market. Current strengths of truck haulage are its flexibility, capacity to offer a custom transport option without much difficulty, and low starting costs. Short distances and difficult to reach locations can be most efficiently supplied by truck.

The ECs of this flexibility, however, are often not incorporated. Increasing awareness of politicians, truck owners, and clients is making these effects increasingly important. The GCA will be able to capture this effect.

One limiting factor that is coming into play more is the introduction of time windows in which trucks may enter urban centers. As a result, it could be argued that the available infrastructure is limited depending on the time or that it has in some places become time-dependent. Although this application for trucks is one of their unique selling points, it is not included given the nature of container transport. On average, city stores are not directly supplied using containers. This application and the corresponding limitations are therefore regarded as outside of the scope of this thesis.

Truck manufacturers are currently working hard on the development of electric trucks [Lambert, 2018]. When internalizing some externalities such as air pollution, it is therefore important to be assured of which externalities are relevant for which scenarios. Cost-wise, the impact of large-scale adoption of electric trucks is difficult to accurately forecast. The considerations will arise again during the CBA and when comparing the generalized transport costs of different transport solutions.

4 Containers

Containers have been mentioned numerous times in the previous chapters. For most readers, especially after reading the past chapter and looking at the figures presented, it should be clear what a container is. Since they are the cargo of interest, however, the specifics of the container are good to know, both for analyzing and concept designing purposes. Since the large-scale adoption of the container as a transport unit, it has undergone changes. Global trade and the world in which it takes place have changed in the past 60 years. This chapter focuses on the container specifics. Dimensions and weights are of interest, as are the transported volumes, journey specifics, and current utilization of containers. The container market is seen as the biggest growth sector in inland navigation. In this case, growth means potential for gaining mode share, resulting in potentially new business opportunities.

This chapter consists of three sections. Section 4.1 begins with the specifications of the container. Using the container leads to costs, which is the subject of Section 4.2. Finally, the current transport market for containers is addressed in Section 4.3. Section 4.4 discusses conclusions.

4.1. Specifications

Container specifics of interest are the dimensions, weights, handling possibilities, and safety. These four topics form the contents for the next four subsections.

4.1.1. Dimensions

The origin of the container can be traced back to 1955, when Malcolm McLean and Keith Tantlinger came up with the idea of a steel box that was 8 feet tall (2.4m), 8 feet wide, and 10 feet long (3.0m) [McGough et al., 2010]. This concept contained a corner mechanism that enabled easy handling, with castings at the corners incorporated into the design. With help of twistlocks, the box can be “grabbed” and handled. Developments in handling equipment led to an increase in container dimensions. The current common container is the TEU. The dimensions of one TEU are provided in the first row of Table 4.1. The other rows list the dimensions of other standard containers that are longer and/or higher than the standard TEU container. Since the container is an American invention, the dimensions are in imperial units. This affects European continental container transport, as will be discussed later on.

Table 4.1: External container dimensions. [Hapag-Lloyd AG, 2016] [Evergreen Marine Corp. Ltd., retrieved 27/02/2018]

Length	Width	Height	Volume	TEU
20 ft (6.1 m)	8 ft (2.44 m)	8 ft 6 in (2.59 m)	1,172 cu ft (33.2 m^3)	1
40 ft (12.2 m)	8 ft (2.44 m)	8 ft 6 in (2.59 m)	2,377 cu ft (67.0 m^3)	2
45 ft (13.7 m)	8 ft (2.44 m)	8 ft 6 in (2.59 m)	3,060 cu ft (86.6 m^3)	2 or 2.25
48 ft (14.6 m)	8 ft (2.44 m)	8 ft 6 in (2.59 m)	3,264 cu ft (92.4 m^3)	2.4
53 ft (16.2 m)	8 ft (2.44 m)	8 ft 6 in (2.59 m)	3,604 cu ft (102.1 m^3)	2.65
High cube				
20 ft (6.1 m)	8 ft (2.44 m)	9 ft 6 in (2.90 m)	1,520 cu ft (43 m^3)	1
40 ft (12.2 m)	8 ft (2.44 m)	9 ft 6 in (2.59 m)	2,660 cu ft (75.3 m^3)	2
45 ft (13.7 m)	8 ft (2.44 m)	9 ft 6 in (2.59 m)	3,040 cu ft (86.1 m^3)	2 or 2.25

The 20-foot container that is currently the most common has a height of 8 feet, 6 inches instead of the original 8 feet. The dimensions provided in Table 4.1 are the current standard. The 48 ft. and 53 ft. containers are most used on the American mainland. In Europe, truck dimensions limit the transportable size of containers.

Twenty-foot equivalent unit containers are actually a fraction shorter than 20 ft. This is done so that two TEUs can be stowed in one 40-foot bay. The actual length of a TEU container is 6,058 mm, while an FEU is 12,192 mm. The difference between two TEUs and one FEU is 76 mm. The “ISO gap” is the official term for this spare room [Lloyd’s Register and The Standard, 2012].

Containers can contain a variety of goods packed in all different kinds of ways. They may be loaded with pallets for further distribution. They can also be filled with individual boxes, bags, or bulk goods. It is not only consumer goods that are transported in containers. In multiple cases, especially within inland shipping, containers are used to collect and transport scraps and waste materials. Scrap metal is still valuable to factories, making it attractive to sell and recycles their waste products such as shavings or cut-offs [Van der Geest et al., 2018].

Increased handling capacity led to the wide adoption of larger containers. The FEU is twice the size of a TEU container. Being direct multiples of each other means that they can easily be used in the same environment. Figure 4.1 shows a stack of containers in which two TEUs support additional FEUs on top. In general, a FEU can be stacked on two TEUs, but not the other way around. A FEU container is not reinforced in the middle to support the castings of stacked TEU containers. This makes certain loading precautions necessary.

(a) Example of a FEU containers stacked on top of two TEU containers [Bätge, 2009]

(b) Overview of container of different size and their stacking options. [D Design, 2014]

Figure 4.1: Stacking examples for different containers.

The standard closed containers that have been mentioned so far do not cover the whole range of existing containers. There are also container types that share dimensional similarities and make use of castings but are somewhat different from the standard container. Some container types that are frequently used but are not standard are listed in Appendix I, Figure I.1. Each of these container types covers a niche of some form. Open tops enable top loading, which is ideal for dumping goods like scraps. Flatracks enable transport of odd-sized cargo such as large pieces of machinery. Reefers enable the transport of perishable goods such as fruit, vegetables, and flowers by controlling the climate inside the container. Tanktainers are used for the shipment of smaller volumes of liquid such as specialized oils. Although all of these types differ substantially, they also follow the same container dimensions. These containers can be stacked and transported with other container types.

Another container type that is gaining attention is the Europa pallet wide type. As previously mentioned, container measurements are expressed in feet and inches, but the Europa is measured in meters and centimeters. The most visible limiting factor finds itself in the euro pallet. The EUR-pallet is 1.2 m long and 0.8 m wide. Given the way it is picked up and putt down, the pallet width of 0.8 m requires a few centimeters of play. The interior width of a TEU are 2.35 meters , making them too small to efficiently place two or three euro pallets next to each other.

Similar to the inefficient loading of containers in current dry bulk holds, there is room to spare when a container is loaded with EUR-pallets. As a solution, a so-called pallet wide container (PWC) was developed in which pallets can be precisely placed next to each other. The outer width of these PWC containers, however, is 2.5 m rather than 2.44 m. Pallet wide containers are primarily used in truck haulage and rarely in IWT [Brolsma, 2013]. They are, however, not left out of this study, because part of the concepts' success lies in supplying urban areas currently using truck haulage. If the improved container (45 ft. PWC) is neglected, it will likely be detrimental to the concept's chances of success.

4.1.2. Weights

Standardization of containers does not end with dimensions. In order to know what to expect during handling, the weight of containers has been maximized. Setting this limit has several advantages. First, road haulers know how heavy the container can be. The ability to stack containers, however, is even more important. With the adoption of maximum weight, maximum stacking height can automatically be safely adopted.

Table 4.2contains the maximum gross container weight. Some sources such as shipping websites, container manufacturers, and other significant bodies such as regulating parties all provide slightly different weights. It is, however, unclear why these "defined" maximum weights are not so fixed as they should be. The main reason that container weights vary is because of different manufacturers and operators [Brolsma, 2013]. Most containers are owned by deep-sea ship owners. Their containers follow the corporate layout , like the white flagged Hamburg Süd containers in Figure 4.1a do.

For ships, stability is of great importance. On large seagoing ships, one container more or less does not make a significant difference. The weight of the containers can vary between the empty weight and the maximum gross weight. To prevent stability issues onboard seagoing vessels, the International Marine Organization's (IMO's) Safety of Lives at Sea (SOLAS) treaty requires per July 2016 mandatory weighing of containers in order to establish the MGW of every container loaded on board [International Maritime Organization, retrieved 05/03/2018].

Table 4.2: Container weight specifics [Evergreen Marine Corp. Ltd., retrieved 27/02/2018] [Hapag-Lloyd AG, 2016]

Length	Maximum Gross Weight	Empty Weight	Net Load
20 ft (6.1 m)	32,500 kg	2,300 kg	30,200 kg
40 ft (12.2 m)	32,500 kg	3,700 kg	28,800 kg
High cube			
40 ft (12.2 m)	32,500 kg	4,300 kg	28,200 kg
45 ft (13.7 m)	32,500 kg	4,700 kg	27,800 kg

For inland navigation, such an obligatory measurement is not required. Inbound containers from ARA upstream have verified gross masses (VGM), leading to better understanding and knowledge regarding the load. Outbound containers may be weighed at inland terminals under certain conditions, meaning that more information will be present for these containers. The weighing follows certain rules, like time between weighing and loading onto the seagoing container vessel. Most containers will, however, comply with these rules.

As previously mentioned, Brolsma Advies [2013] has performed a study on container height on inland vessels in the Netherlands. They have provided findings regarding the weights and trends in container weight at several important measuring points. Figure 4.2 illustrates these measurement results over a period of 10 years. The figure's lines follow either stagnating or slowly declining trend. In order to fully understand the graph, Brolsma [2013] has provided the following additional text:

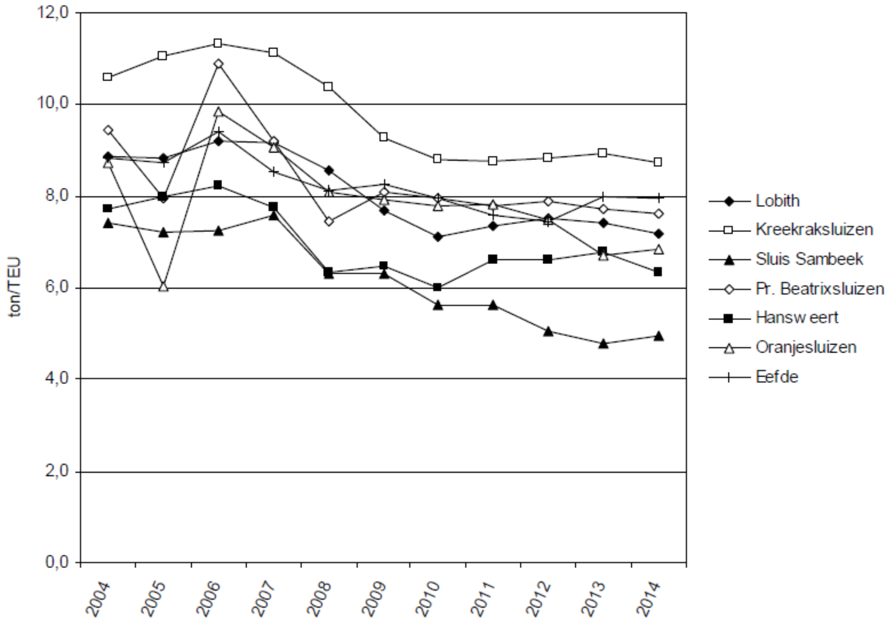


Figure 4.2: Development of average IWT container weight over a 10 year period for several measurement point spread throughout The Netherlands. [Brolsma, 2013]

'The average of the two, by far the most important waterways, de Waal and the Scheldt-Rhine connection is around 8.0 tonnes/TEU. Based on previous research it was found that on average 65% of the containers on board is loaded. The net weight of the average loaded container than is: 8.0/0.65 = 12.3 tonnes per TEU. Including the weight of the container itself, being 2.0 tonnes per TEU, the total weight of a loaded container comes at 14.3 tonnes per TEU. [Brolsma, 2013]'

Analyzing this explanation provides important information regarding the assumptions made for containers to be transported by the concept ship:

1. On average, 65% of transported containers on inland ships are loaded, leaving 35% empty containers..
2. The weight of the container itself may not be neglected, as this is approximately 2 tonnes per TEU (e.g., 2 / 14.3 * 100% = 14% of the total container weight). This means that on average, seven empty TEU containers weigh the same as one average loaded TEU container.
3. Deep-sea container shipping is increasingly using ultra large container carriers (ULCCs). This results in very large amounts of containers being delivered and demanded at once. As a result, the need for large inland vessels (CEMT Va, VLa, and combined barges) is growing.
4. The average container vessel is loaded with 65% of its TEU capacity.
5. Twenty percent to 32% of current containers are HCs, which are ideal for voluminous cargo with low weights. In 1996, only 7% of containers were HCs, so a three to nearly five-fold increase has occurred.
6. Sixty percent of containers on inland vessels are TEUs or FEUs. More than 50% of the FEUs are HCs, and this number is increasing quickly, because more than 90% of new FEUs are HCs. Within 15 years, which is the lifecycle of an average container, HC will become the standard.

7. Forty-five-foot containers were popular for a while, but this increase has faltered because these containers are mainly used for SSS towards the UK. This specific trade is primarily distributed via truck.
8. Reefer shipping is growing steadily. Reefers are, however, 2 inches or 5 centimeters higher than standard containers.
9. Wide-bodies, or pallet-wide containers, are primarily used in trucking and are virtually never used in inland shipping.

Van der Maaten [2002] has performed a study researching a very large inland terminal complex called Valburg, which is located near Nijmegen in the Netherlands. In order to predict the amount and type of containers to be expected, he has provided a container division by rough type. What he found was that 98% of containers could be labeled as standard, meaning 20' or 40' long, and between 8' and 9'6" high and 8' wide. This includes both the basic container and the reefer version.

Two percent of the containers were non-standard, of which 1% were longer than 40', 0.7% were higher or wider than the standard, 0.2% were completely different, such as open-tops, and only 0.1% were IMO-labeled (this label is put on dangerous cargo).

For the remainder of this research the non-standard containers are left out, because it simply is too much work to keep incorporating them into the designs when in practice they are likely not making a mode shift towards the small-scale IWT concept. Reefer containers are included because their share in sea trade containers has been steadily rising to 11% in 2012 [Rodrigue, 2014] [World Shipping Council, 2011]. It is important to keep in mind that “reefer” does not necessarily mean super cold storage. The conditions inside a reefer can range between -35°C and 14°C [Rodrigue, 2014].

Focus is placed on regular height 20-foot and 40-foot and HC 40-foot and 45-foot containers. Forty-foot pallet wide containers are also incorporated. The respective size share is estimated to be 35%/60%/5% for 20/40/45-foot containers. Forty-foot containers are estimated to be split 75%/25% between HC and non-HC height. All 45-foot containers are deemed HC. Pallet wide containers make up 5% of the 40 and 45-foot containers, since they are just beginning to enter the market at a noticeable level.

The average TEU weight measured was 12.3 tons. For reasons of convenience, rounding this somewhat this leads to the following assumed weight for several containers in Table 4.3.

Table 4.3: Assumed container weight for different containers under empty and loaded conditions. (All weights are in tons)

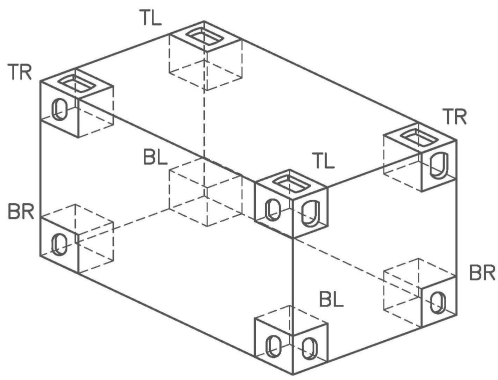
Loading condition →		Empty = Tare	Loaded (incl. own weight)	
Container type ↓		Min	Average	Max
Standard	20	2.5	15	32
	40	4	29	32
High Cube	40	4.5	30	32
	45	5	30	32

4.1.3. Castings and Twist-locks

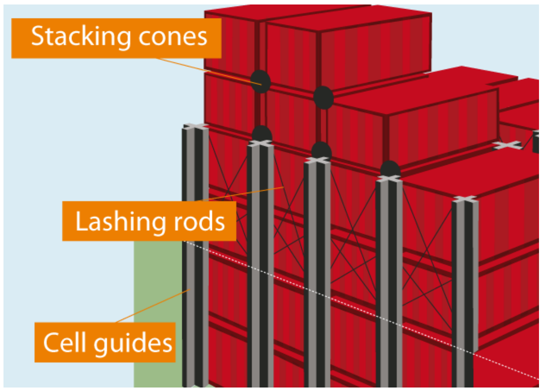
A large part of the success of container lies in its ingenious use of corner points known as castings. These fittings enable easy and robust handling of the container. The castings themselves are strong points in the container design. They contain three holes, of which the top hole is used for grabbing the container. This bulged hole is used for the twistlock system to grab onto. When the twistlock is its unlocked position, the castings' opening can slide over the locking pin. Rotating the pin 90 degrees then locks the container, because the locking pin cannot get out of the castings' opening. The two openings that are also present in the castings are used for additional lashing attachment. In IWT, these lashing pins are rarely used.

Lashing is primarily used on seagoing container carriers [Lloyd's Register and The Standard, 2012]. Weather conditions such as wind and waves are far more extreme at sea than those experienced in inland navigation are. Rail and road will always secure the containers with the twistlock system in the bottom castings. Inland navigation often has a maximum of two or three layers exposed to the weather. For large, dedicated inland container carriers, cell guides are often installed.

Stacking cones are double-sided, twistlock-shaped cones, securing a connection between the top casting of the lower container and the lower casting of the upper container. Such a connection is not as rigid as a twistlock that locks the casting. These stacking cones are primarily used to prevent horizontal slipping of containers above the coaming. One important difference between the types of securing equipment is the need for manual installation. A twistlock system is equipped with a lever, enabling the use of the locking mechanism. During or after the loading of containers, stevedores have to pull the levers or attach and buckle the lashings. Unloading requires the exact opposite procedure. This is an important notice, because automated transshipment on inland vessels would exclude human interference. Development of self-locking and unlocking containers is too farfetched excluding this possibility. A solution for securing containers has to be found in the direction of cell guides.



(a) Schematic overview of corner castings and their location in the container [Chassis King, retrieved 27/02/2018]



(b) Schematic overview of corner castings and their location in the container [Chemical Pollution, retrieved 28/02/2018]

Figure 4.3: Overview of container handling and securing options

4.1.4. Safety

Containerization has removed cargo out of direct sight. This would have made the container a black box had it not been the case that there are rules to follow. In order to prevent accidents caused by the transport of dangerous cargo, the Accord Européen relatif au Transport International des Marchandises Dangereuses par voie de Navigation du Rhin (ADNR) was written. In 2008, these rules were altered and replaced by the Accord du transport Dangereux par voie Navigable (European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways, or ADN) [UNECE, retrieved 05/03/2018]. [UNECE, retrieved 05/03/2018].

One of the rules of the ADN is the requirement of separation of ADN containers. Two containers that are marked "AND" should be separated by at least 8 meters [CCR EBU ESO Aquapol, 2015]. Digital stowage computers help to ensure that the ADN rules are followed. There are also rules for the transportation of dangerous goods via rail and road. There are similar rules for road transport also referred to as ADR, with the "R" now standing for "Route" in French and "Road" in English [Evofenedex, retrieved 05/03/2018]. The rules regarding rail transport are referred to as Regulations Concerning the International Transport of Dangerous Goods by Rail (RID) [Rijksoverheid, 2017].

4.2. Costs of Using Containers

The cost of using a container results from both the cost of hire and the cost of loss of business opportunity. Both are discussed in the following two subsections.

4.2.1. Container's Own Costs

Although a container is nothing more than a box enabling intermodal operations, the box itself if an interesting piece of equipment. This intermodal loading unit does not only enable transport, but it has its own associated costs. A new 45' container costs approximately €6,500 and has a residual value of €1,000 after 10 years of use [Van Dorsser, 2015]. Annual R&M of the container is approximately 5% of the initial value, or €325. These numbers are all for the base year 2010.

The price of a newbuild container did crash by almost 60% after the fourth quarter (Q4) of 2010, hitting an all-time low in Q1 2016 Van Leeuwen [2018]. The main reason for this crash was a drop in the price of hot-rolled Chinese steel from $600 per ton in 2010 to $350 per ton in 2016. At the beginning of Q4 2017, the average domestic Chinese hot-rolled steel price was $560 [Mercier et al., 2018].

The development in newbuild container prices is outlined in Figure 4.4. A 40-foot container is 1.6 times as expensive as a 20-foot container [Van Leeuwen, 2018]. Analyzing Figure 4.4 indicates that the Q1 2016 price for a 20-foot China/ex-factory container was around $1,300–$1,500 USD. The 40-foot HC cost $2,200–$2,400. These values correspond to €1,180–€1,360 for the 20-foot box and €2,000–€2,180 for the 40-foot HC. [1]

Unlike Van Dorsser [2015], who assumed a 10-year lifetime, Van Leeuwen [2018] has stated that the useful life of a container is more in the region of 12–15 years. As a result, a 12-year lifecycle is therefore adopted in this study. While Van Dorsser has assumed a €1,000 residual value given the low 2016 cost levels, the residual values are likely to be even lower. The assumed residual values are listed in Table 4.4 and, according to Van Leeuwen, follow the newbuild prices.

Since only the costs of 20-foot and 40-foot HCs are provided, the 40-foot and 45-foot HC values are extrapolated. The 40-foot container is assumed to be 10% cheaper than the 40-foot HC. The 45-foot HC is assumed to be less common and thereby 20% more expensive than a 40-foot HC. Scaling leads to the values listed in Table 4.4. These values are all China/ex-factory, meaning that the cost of the first transport to Europe is not included. In extreme cases, these costs can be as much as the initial value [Van Leeuwen, 2018]. This is, of course, the extreme, and therefore it is assumed that one should add 50% of the bare newbuild price to the effective newbuild price.

Forecasting the daily rent tariffs is done in keeping with the method proposed by Van Dorsser [2015]. Linear depreciation leads to annual depreciation costs. Together with the R&M, the annual costs for owning a container are approximated. The minimum rent cost for a container is calculated under the assumptions that the container is in use 180 days per year and that a 10% overhead rate is applied on these used days. While steel was very expensive in 2010, it was far cheaper earlier in 2018. As a result, the average rent cost following the method came down from €4.58 per day to €3.06 per day. An overall rent value of €4 per day is therefore adopted to average out the varying steel price and the resulting container newbuild cost.

Table 4.4: Newbuild and residual value of the most common container type.

Year	2016 Cost (EUR/USD = 0.907)		2018 Cost (EUR/USD = 0.814)	
Container type	New	Used	New	Used
20	$ 1,400	$ 500	$ 2,200	$ 800
40	$ 2,100	$ 900	$ 3,200	$ 1,400
40 HC	$ 2,300	$ 1,000	$ 3,500	$ 1,500
45 HC	$ 2,800	$ 1,200	$ 4,300	$ 1,900
20	€ 1,300	€ 500	€ 1,800	€ 700
40	€ 1,900	€ 800	€ 2,600	€ 1,100
40 HC	€ 2,100	€ 900	€ 2,800	€ 1,200
45 HC	€ 2,500	€ 1,100	€ 3,500	€ 1,500

[1] US Dollar to Euro exchange rate was on average 0.907 euro/dollar according to the historical OECD statics

Table 4.5: Cost of renting a container per day (based on calculations and estimations by Van Dorsser [2015])

Container type	Daily rent cost (2010)	2018 updated rent cost
20	€ 3.31	€ 2.26
40	€ 4.77	€ 3.24
40 HC	€ 5.30	€ 3.48
45 HC	€ 6.36	€ 4.35
Average	€ 4.58	€ 3.06

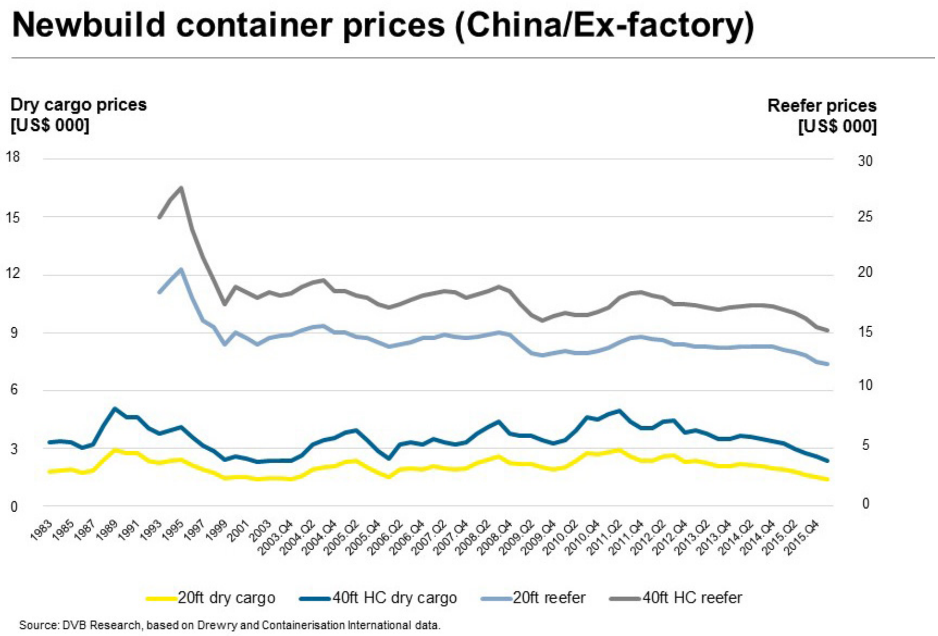


Figure 4.4: Development of the newbuild container prices (China/Ex-factory) (Retrieved from Van Leeuwen [2018] with original from Drewry Container Census & Leasing Industry Annual Report 2016)

4.2.2. Time Value of a (Loaded) Container

In addition to the box's costs, the payload itself has a value that adds a certain time sensitivity. This is known as the time value of the transported goods. The capital costs of the goods and the loss of business opportunities during shipment form these costs.

Based on calculations and assumptions, Van Dorsser [2015] has estimated time value at €14.27 per full 45-foot container per day. Reproducing these values, backing his estimations, and extrapolating his values to 2018 levels is extremely difficult to do.

A similar approach is used starting with valuing the average value of the cargo. This is done by dividing the value of transported goods by the total transported weight. The type of goods and the type of region are extremely important to these calculations [CBS, 2017]. For example, building materials have low value and high weight, while machines have relatively more value compared to the same weight. Additionally, the values of incoming and outgoing products differ. This can be explained by the fact that the studied region may be regarded as a value-adding region that has extensive knowledge and skills.

The average value of European imported goods was €792.14 per ton (ranging between min/max → €664.59/€887.13), and exported goods had an average cost per ton of €1,122.96 (€1,033.15/€1,208.95 for the base year 2010). For higher valued goods such as the previously mentioned machinery, the value was around €4,100 per imported ton and €6,650 per exported ton.

Given this large range of goods' values and the anticipated diversity in containerized goods, the assumed value has to be estimated. The following assumptions are therefore made: for imported containers, the value is set at €1,500 per ton, and exported cargo is given a level of €2,500 per ton. Containers not leaving the delta are presumed to have a value of €2,000 per ton (base year = 2018).

The WACC of the containerized cargo is assumed to be 6% in line with research conducted by Hekkenberg [2013] and Van Dorsser [2015]. The markup assumed by the latter is 25%. This seems very high, especially for inland transported goods that are undertaking trips of days instead of weeks. The markup for the loss of business opportunity is therefore assumed to be 10%. As a result, the numbers listed in Table 4.6 are assumed as the time values for containerized goods. The lower values are daily costs per full box. Overall, the time value of containerized goods is €8.90 per box per day. To prevent calculation difficulties when these costs are split, the time value used is €9.00 per day.

Table 4.6: Time value of containerized goods. (base year = 2018, results of own assumptions and calculations based on Van Dorsser [2015])

Containertype and weight →		20	40	40 HC	45 HC
	Value (€/ton) ↓	15 ton	29 ton	30 ton	30 ton
Import	€ 1,500.00	€ 22,500.00	€ 43,500.00	€ 45,000.00	€ 45,000.00
Intra-delta	€ 2,000.00	€ 30,000.00	€ 58,000.00	€ 60,000.00	€ 60,000.00
Export	€ 2,500.00	€ 37,500.00	€ 72,500.00	€ 75,000.00	€ 75,000.00
WACC = 6%		€ 4.07	€ 7.87	€ 8.14	€ 8.14
Mark-up = 10%		€ 5.42	€ 10.49	€ 10.85	€ 10.85
Annual days = 365		€ 6.78	€ 13.11	€ 13.56	€ 13.56
Overall Average		€ 8.90			

4.3. Inland Container Market Expectancy

So far, the structural and financial specifics of the container have been established. The market of containerized goods is, however, increasing allowing for a market forecast [CCR, 2017]. This section discusses forecasting remarks applicable to the container market. In addition, a brief expectancy is presented.

4.3.1. Cargo Forecasting Remarks

Following the container specifics, it is necessary to gain insight into the potential of container transport. Before an analysis is made, it is important to take notice of the forecast of interest. Forecasting is almost always an educated guess closely related to insecurities. As a result, a forecast may not be taken as always true or exact. An expected 5% in five years may be the average of an expectancy band between 2.5% and 7.5%. In 10 years, this band may range from -5% to +15%. Since the future depends on so many factors, a change being either expected or unexpected may have insignificant or significant results. For the local transport sector (within the region of interest), global trade is significantly depended on. As seen following the crisis of Q4 2008, the world's economies' growth can turn on a dime and change into a recession with record lows for the transport sector. It is therefore important to realize that the forecast should be taken with a grain of salt.

Another important remark must be made concerning the period of interest. The goal of this research is to investigate automated container handling aboard inland vessels. A ship's lifecycle ranges between 25 years for seagoing vessels to multiple decades for inland vessels. The economic lifecycles for these ships differ and are normally longer, since after recouping investments the true money can be made. For inland ships this means that at most the coming two decades are of interest when keeping the financial investments in mind. After a vessel is engineered, financed, built, tested, and fully operational a certain amount of time will have passed. This period is not precisely specified. It is, however, probable that this process takes upward of a year, with a rough realistic maximum of three years. What happen in this period is of less interest for the investment proposal, since the ship will not be operating during that time. When the proposal is passed, the short-term market conditions might become of greater interest, because they can lead to advancing or postponing the construction. The business case in Part IV contains more of these financial specifics.

Strictly speaking, containers themselves are not cargo. They are only a structural packaging for a variety of cargo types including machines, consumer goods, food, clothing, small parcels of liquids, metals, scrap, chemicals, and more. In most cargo forecasting reports the container is not mentioned when the types of goods and their relative shares are discussed. As a result, it can be difficult to forecast drivers of increased container transport. Containerization is still rising [CCR, 2016], with the main driver being the low costs. Whether the user of the container sees this opportunity is difficult to predict. Part of the success of road transport is the flashy presence of the modality with its speed and easy use. Luckily, large ports such as the ARA ports and major inland terminals are also interested in TEU volumes, which provides some insight in container trends.

4.3.2. Cargo Forecast

Containerization is less than a century old and will continue to increase in volume. Beginning at a global scale, the world population and the spending per capita will keep on increasing. In the coming century, the digitalization of global trade will increase significantly. Looking at the forecasts as they are now, global trade is expected to grow by approximately 4% annually in the medium term [Van der Meulen et al., 2018].

Examining container transport throughout the delta, there is a distinction between two types of trade, namely inland and international trade, which are often referred to as import and export. For the former, Van der Meulen et al. [2018] have estimated a total weight growth of 22.7% for the coming five-year period. The transport performance, which is the product of weight and distance covered, even is expected to increase by 38%.

For export out of the Netherlands, Van der Meulen et al. [2018] have forecasted a 5.1% growth of total transported container weight during the period from 2018 to 2022. The export transport performance is expected to grow 3.6%. For import to the Netherlands these forecasts are 10.5% and 10.2% for transported weight resp. transport performance.

As explained in the second chapter, forecasting is of limited use for the chosen approach. It is, however, promising that in all forecasts the volume, weight, and market share of container transport is expected to grow. For the concepts introduced in this thesis this means that the cargo volume they attract is more likely to grow than to decline, reducing the risk of cargo loss.

Every year the CCR provides a market review of the previous year. These documents show insight in the performance development of IWT. In the 2016 report a valuable connotation was provided regarding the container transport market for IWT. The report stated that although the container transport sector is still a growth market, the developments over the past years do not follow the trend of transported TEU amounts. The most likely cause for this is the period of low water levels leading to a low water level price markup. With the increased prices, the price advantage compared to rail, for example, is lost. These price fluctuations characterize the entire IWT market, container shipping included.

What makes forecasting so difficult is the fact that not only are a certain amount of containers from known clients likely to grow annually, but the amount of terminal users is likely to increase in the beginning. A great example is the container shuttle service on the river Moselle in Germany. In 2013, 3,600 TEU were registered at Koblenz, which is the junction point of the Moselle with the Rhine [CCR, 2016]. 2014 saw this level rise to 5,200 TEU, and 2015 to 11,000 TEU. It is expected that 2030 will see 100,000 TEU transported via that shuttle service [Van der Meulen et al., 2018]. This is a 19% year-on-year growth for a 17-year period, leading to an almost 20-fold amount of transported TEU, which reinforces the idea that finding the right niche market can reap major annual growth for a long period of time.

4.4. Intermediate Conclusions Chapter 4

This entire chapter discussed different aspects of the cargo under consideration. However, it is important to note that the container comprises both cargo and some type of transport packaging material. The contents of the container have not been discussed because they are of little interest to the ship and terminal owner during concept design.

Although the most common container types are standard, their uses and shares are constantly changing. There has been a substantial rise in the use of HC containers, which will lead to higher air draught and less containers being stacked on inland vessels. It is especially important to carefully examine the shares that will be carried for inland shipping on small waterways. When air draught is limited, less containers can be stacked, which leads to higher costs per container.

Less frequently used container types include the pallet-wide container (PWC) and the container depicted in appendix I; these containers have been left out from this study. These containers' common dimensions allow them to be carried together with regular containers but their special contents often require additional service. It is to be determined whether the concept could easily allow for these types of special containers. When substantial additional investments must be made before these tanktainers can shipped these are most likely irrecoupable as their transport volume is very low. Offering synchromodal alternatives over road and/or large IWT could be beneficial in this case.

The costs for using the container and the time value of the containers contents are relatively low: ≤ €50. It is best to incorporate these costs to prevent skewed comparison when only a marginal difference is found. This will prevent wrong impressions because the numbers do not represent all aspects.

This chapter also discussed container weights. The average TEU weight (including tare weight) was found to be 15 tons. This does not mean, however, that the average TEU container weighs 15 tons and an average FEU container (twice the weight of a TEU) weighs 30 tons. In reality, the TEU container will be used for cargoes of higher density. These contents are therefore weight critical. Larger containers are more likely to be used to carry cargo of less dense material. This cargo is volume critical. Table 4.7 illustrates an example. Although the TEU is heavier than the FEU, and both are heavier than 15 tons, the average weight of the TEU is 15 tons. This example should underline that although the average weight is important, averages are not definitive of the individual container.

Table 4.7: Example of the weights of both TEU and FEU containers.

Container	TEU equivalent	Weight	Weight per TEU
TEU	1 TEU	25 tons	25 tons per TEU
FEU	2 TEU	20 tons	10 tons per TEU
Sum	3 TEU and 45 tons in total		
Average weight =	15 tons per TEU		

5

Inland Container Terminals, Handling and Costs

This fourth chapter of Part II analyzes the inland terminal and its cost characteristics. This is the third key piece of the transport chain, together with the transport modes and transported cargo, that enables intermodality. With their current characteristics, inland terminals are unable to revolutionarily penetrate the capillaries of the IWT network and revitalize small waterway IWT.

In order to develop and propose a simplified, competitive, and profitable concept, the current *modus operandi* is first analyzed. A start is made with the abstraction of processes that define the inland container terminal. The current terminals' designs are based on these processes. For any renewed concept it is therefore best to incorporate the process analysis.

How the processes are currently given shape with what equipment is analyzed next. The current modus operandi has (cost) characteristics consisting of o.a. throughput and cost buildup. This thesis' concepts should outperform one or more of these current characteristics to become the preferred option. Concepts must not internalize existing bottlenecks, but should begin from a blank canvas to ensure optimal operations to eliminate current shortcomings. Additionally, it is valuable to know how the different cost factors influence the overall terminal minimum tariff. Keeping the holistic approach in mind, improvements of one specific aspect might overall turn out to be harmful in another area. Lessons learned during the analysis are used in Chapter 8 to propose new concept designs and principles.

Section 5.1 begins with an overview of the general terminal processes. The terminal-defining handling steps are described and clarified. After this, specific pieces of terminal design are researched. Equipment, its application, and costs are analyzed step-by-step in Section 5.2. This analysis is performed in order to find improvements and to gain understanding of the considerations that have led to the current situation. Section 5.3 contains a cost-level analysis of existing inland terminals based on research literature. The relative contribution of capital cost, site-specific cost, and labor and equipment, for example, are analyzed. Based on the literature review, current terminals have (potential) bottlenecks in their operations. These are the subject, together with some more general notations, of Section 5.4. The resulting starting points for the terminal design concept is the subject of Section 5.5, where the intermediate conclusions are drawn.

5.1. General Handling Process

This section presents an overview of the general terminal processes. The terminal-defining handling steps are described and clarified. Subsection 5.1.1 begins with the abstracted handling processes. This abstract representation presents the terminal in its most basic form and with its primary basis. Such an abstract representation is not, however, found in practice, but is translated to a handling process in practice. Subsection 5.1.2 elaborates on the way how this is translated to reality.

5.1.1. Abstracted Handling Processes

When analyzing the handling processes at inland terminals, it is important to define what the term “handling” means. Handling contains all processes related to the movement of containers inside and across the boundaries of a terminal. This can vary from loading and unloading at the perimeter to stack rearrangement. Rademaker [2007] has provided a schematic overview that defines the processes of a terminal. Rademaker [2007] has also performed a study of the feasibility of automation for mid-sized terminals (200.000 TEU). Although his research has focused on terminals larger than that are to be expected in this research, some of his findings are still helpful. In his analysis of terminal procedures, he has proposed the systematization that is illustrated in Figure 5.1. A remark in place is, however, that for most inland terminals, the horizontal transport portion is internalized in the yard handling process. As a result, an improved version could be proposed that might better represent the process steps experienced at inland terminals.

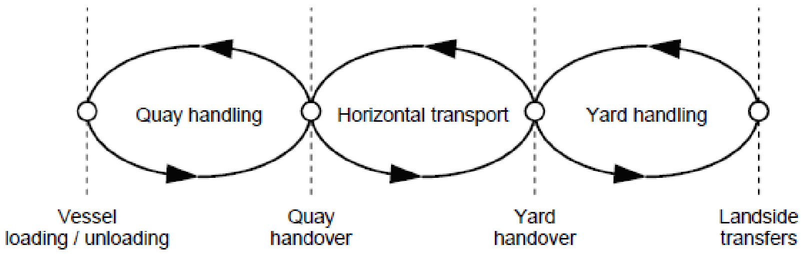


Figure 5.1: Schematic overview of system cycles: quay and yard handling. (Original by Rademaker [2007])

Modifying Rademaker’s schematic representation has led to the schematization illustrated in Figure 5.2. From this point onwards, these three handling procedures are used for both the analysis of inland terminals and the development of concepts.

The quay handling occurs at the waterfront and consists of the loading and unloading of vessels. Ships are served at this end. Containers effectively cross the terminal’s perimeter, making this part of the handling process, as previously mentioned.

On the other side of the figure is the gate handling. At this end, land-bounded modes are served. This end of the terminal connects IWT to the pre-haulage and post-haulage (PPH) activities, and vice versa. This part could be abstracted by referring to it as the dry quay. Again, containers effectively cross the perimeter here.

The yard handling process takes place in between these other two steps and entails all container handling from either the moment the container is outside of the vessel and above land on the wet side, or as soon as the container is taken from the truck or train on the dry side. Yard handling mainly consists of stack rearrangement and buffering for the supply & demand of containers at either end of the yard, and the movement of containers across the terminal.

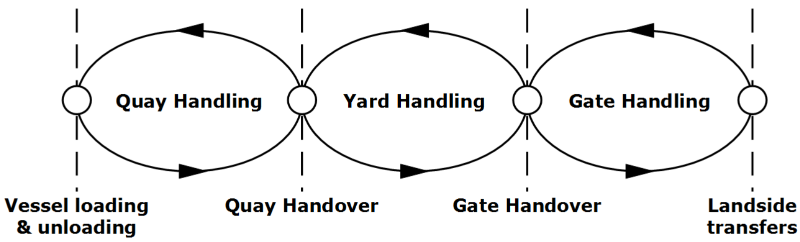


Figure 5.2: Schematic overview of system cycles for an inland terminal. (Source = own work, based on Rademaker [2007])

These three sub-handling cycles and four handover points are used in Chapter 8 when designing new concepts. Using the three handling cycles, for instance, it is possible to deduce that the cycle with the slowest handling speed/capacity could lead to a bottleneck. For a just-in-time (JIT) terminal gate, for example, the handling speed should be roughly equal to the yard handling speed in order to prevent idle and/or waiting time.

The handover points are the only opportunity to change the cycle. Fast quay equipment that fills the quay will then have to wait for containers to be taken by the yard handling cycle before it can resume quay handling. Its superior capabilities will therefore be nullified.

Again, this highlights the importance of a holistic approach to terminal design. Focusing on a specific operation or piece of equipment that does not resolve bottlenecks elsewhere has a low chance of success.

5.1.2. Handling Processes in Practice

How these processes are currently arranged is (partly) caused by site-specific conditions and the market or competition. External conditions can include waterway restrictions, noise restrictions, the presence of natural limitations, terminal dimensions, or the undesirability of the sight of container stacks. For the concept phase, enabling scalability can solve problems such as this. For example, with the development of Port of Rotterdam's inland container transferium, the government has limited the size with a view to safeguarding the environment and quality of life [Van Schuylenburg and Borsodi, 2010].

To use Rademaker's [2007] terms, the market consists of both requirements and demand. The demand or request for transported containers is a key factor in deciding the terminal's dimensions. Given the concept terminal's intended small scale and low cost, the dimensions are kept free in order to optimize the terminal. For example, if land prices are high, a smaller terminal might be necessary, but if land is cheap, a more spacious layout may be possible. Smaller vessels automatically lead to smaller call sizes, reducing the amount of trucks and the size of the stack that is required. Abstracting these means that the throughput volume, frequency, and special requirement determine the terminal's optimal capacity.

For small-scale inland terminals, the quay length and dry quay capacity are less important, because the terminal will handle one vessel at a time. The operating scheme in place is a result of the demand for transport by clients and the supply of transport by a ship owner. For example, this could be one shipment per week of 100 TEU. When the container throughput volume increases due to increased demand, supply of the service can grow. In many cases it is then more favorable to first increase the sailing frequency to, for example, two shipments per week (i.e., every three days) than to increase the vessel's size to 200 TEU [Konings, 2003]. This has to do with the value or valuation of time (VoT) by clients. Increasing the frequency to the other extreme of multiple ships sailing per day is also not favorable given the VoT. At a certain frequency, the time gained by earlier departure is less than the reduced cost that could be achieved by operating a larger vessel. As a result an optimum is in play, justifying or even requiring keeping the concept terminal scalable in order to find this optimum. An overview of the actuator model that provides insight into the deciding factors for the terminal size is provided by Saanen [2004] and illustrated in Figure 5.3.

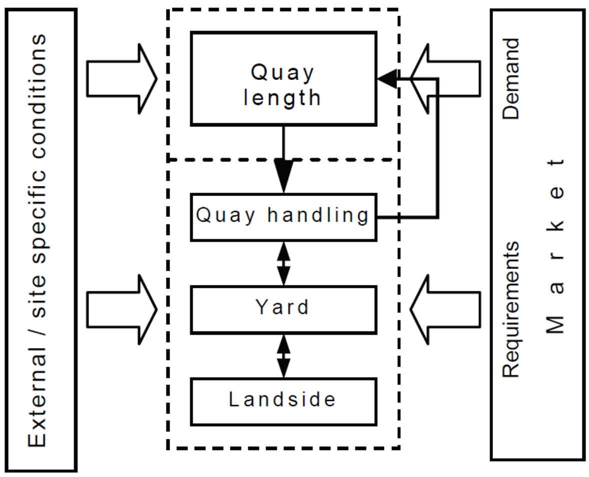


Figure 5.3: Overview of influencing aspects on the functional design. [Saanen, 2004]

The purpose of inland terminals is to link inland waterway transport with continental, land-bound transportation networks, thereby enabling intermodal connections. In that role, the two main functions of the inland terminal are transshipment of containers from one mode to another and storage of containers for a period in between shipments. Equally so, but to a lesser extent , the terminal can function as a hub in one of the separate networks. This can be, for example, ship-to-ship when the loads of smaller vessels are bundled, or vice versa. For this study, the hub function for multimodal transport of truck-to-truck and especially train-to-train is of less interest. Truck-to-truck hubs require other types of facilities than those generally offered by a small-scale terminal. An example is mentioned in the cargo forecast in Section 4.3.2. Operations such as this do not, however, require radically different terminal designs other than a larger stacking facility, since the throughput volume likely increases.

Studying the work of Saanen [2004] even further it appears that he places considerable emphasis on the storage functionality of a terminal. He provides the following overview:

The storage functionality should not be underestimated: container terminals provide a relatively inexpensive, secure, easily accessible location, from which just-in-time delivery of containers can take place. The reasons that the storage functionality of a marine container terminal is essential are summarised [Van Zijderveld, 1995]:

1. *Direct transhipment would make the processes at the terminal too complex; in case of transhipment from a deepsea vessel onto trucks, this would result in a complex controlling of all individual trucks, to make sure that they arrive in the right order at the right time to get their container.*
2. *Direct transhipment would yield a complex terminal design for those terminals that include more than two modes of transport: All modes of transport that are handled would come very close to each other, which would immediately cause difficulties for terminals that include barges, deepsea vessels, trucks and trains.*
3. *Direct transhipment would require the simultaneous presence of both means of transport between which load units are transshipped. Especially direct transhipment of load units between deepsea vessels and trains or even between vessels is virtually impossible due to the great diversity of destinations of load units, the strict loading sequences of trains and vessels, and the length of trains.*
4. *The owners of containers do not always need their cargo immediately after the arrival of a container. Also, customs demands (fulfilment of duties) and financial requirements will cause the need to store the container(s) at the container terminal. As research by Van der Rakt [2002] shows, some containers stay more than 6 months at the deepsea terminal.*

Although these remarks are deep-sea terminal-specific, similar considerations have to be made for inland terminals. For the second point, for instance, the direct handling of a container from/to a vessel to/from a truck for one or two containers is not problematic. When a large number of containers require handling, numerous trucks would have to come to the quay, making the operations too difficult and likely to cause delays.

Points 2 and 3 of the enumeration also have potential. At small-scale inland terminals, call sizes are correspondingly small. This means that direct transshipment to and from trucks, primarily, can be a great USP. Compared to larger inland terminal that is hesitant to accept direct transshipment and/or requires a premium for this service, the small-scale terminal could offer a direct handling service that is beneficial to all parties.

Direct transshipment does, for example, lead to fewer moves via equipment and reduce the need for – and thereby the size of – the storage facility. For the clients, their container(s) are available at an earlier time, enabling swifter business.

Congestion at the landside transfer area is, however, looming. When a primary piece of equipment is used, as is currently the case with the wide-span gantry crane terminals, the additional usage for the gate handling cycle has the potential to delay the other terminal processes. Zehendner and Feillet [2014] have demonstrated that a truck appointing system could mitigate this risk and could reduce internal congestion of current terminals by 5%.

The fact that the owner does not necessarily require the container directly after arrival at the terminal creates the need for storage. For intercontinental or short sea containers, storage can occur either at an ARA port or at the conceptualized inland terminal. Given the capacity limits for the ARA ports [Dijkhuizen, 2017a], it may be beneficial to store the container closer to the destination or origin. If the container is then requested to be delivered, it is available at shorter notice, enabling JIT operations. Additionally, the price of storage at the deep-sea and inland terminals can dictate where the container is stored. When it turns out that the container can be stored at a lower price at the inland terminal, the container is likely to be stored there. To a certain extent, it could even be that given a certain capacity, the price may be set to increase/decrease the demand for storage. Lowering the price will result in more storage, and vice versa. The price elasticity of demand for container storage is, however, difficult to forecast given the wide variety of goods containers can carry. For a client, an empty container is virtually worthless, while a container loaded with high-tech equipment might be worth more than €1 million. For the terminal, all boxes could be considered valuable. A still-standing trailer bed with an empty container on top could cost a haulage company significant money because it cannot use its trailer. Getting rid of the container by temporarily storing it at the terminal could then lead to a double gain. In this scenario, the haulage company could use its trailer while the terminal would receive payment for the storage. More consideration concerning the storage capacity and the elasticity of demand can be found in Section 8.6.

In most larger maritime, deep-sea terminals, the terminal has secondary functions, as Hekman [2001] has mentioned. Empty containers are stored at these terminals, but due to limited capacity, this storage location is expensive. Consolidation of cargo takes place in the container freight station (CFS) where the "less than container loads" (LCL) with different destinations or origins are handled. They are loaded into (at origin) or unloaded from (at destination) containers. This is outside of the scope of this thesis because it is no longer intermodal freight when the container is opened. For inland terminals, these facilities are relatively expensive and are therefore not always incorporated. Keeping the concept development purpose in mind, LCL handling is not to be expected at the automated terminal and is therefore left out of the conceptualization.

According to Hekman [2001], a terminal also serves a backup function. This function supports the performance of the other three functions (transshipment, storage, and consolidation). Examples include a maintenance shop for equipment and facilities, and container-handling equipment inspection and repair. For inland terminals, such a function is normally limited. The simplistic, low-cost concept excludes this function.

By distilling the insight gained, the following image is created: quay operations are vital for interaction with inland vessels. There is a tension field between capacity supplied and demanded. From the carriers' perspective, quay operations cost valuable time. The carrier would ideally see its vehicle/ship/train (un)loaded in the shortest possible time so that it can do what it is designed to do, which is haul containers.

For the terminal operator, the handling of cargo is one of its main sources of income. Handling all containers in short time periods automatically means that the equipment is idle during long periods in between calls. This is then most likely costing the terminal operator money, because he/she cannot recoup the cost of the equipment. On-time handling is important; therefore, cost and volume considerations determine the choice of equipment used at this step. This is discussed in greater detail in Section 5.3.

The storage facility should be considered as the backbone of the terminal. It is the enabler of swift handling at either terminal end. At the same time, storage acts as a buffer of arriving and leaving containers. Additionally, it can play an important role for empty containers. Operating the terminal correctly enables smooth handling, which in turn increases the terminal's attractiveness. A fully optimized terminal may in practice be difficult to work with when, for instance, the expected container is not on time. When designing the concepts, it is therefore important to remember that the terminal should be workable in practice. If the forecast for profitable operational procedures is very near perfection and this level is not achieved in practice, the deemed optimum is not viable in the long term.

To further define the requirements, a choice is made regarding the purpose and use of the conceptualized terminal. Saanen [2004] has incorporated a domestic cycle between the incoming and outgoing landside flows. As previously mentioned, the local-to-local truck-to-truck and train-to-train flows are deemed unlikely. An adapted version of the original by Saanen [2004] is therefore provided in Figure 5.4. Looking back at the background and the resulting scope, emphasis is put on enabling intermodal transport between IWT and road, combined with rail when economically feasible. The inland terminal will primarily be designed to enable small vessel IWT to penetrate the capillaries of the network. The facility as a local-to-local container hub for road and rail is expected to be non-viable because flows are too small. If the business plan requires additional sources of income to become viable, new interest might be pointed towards this process.

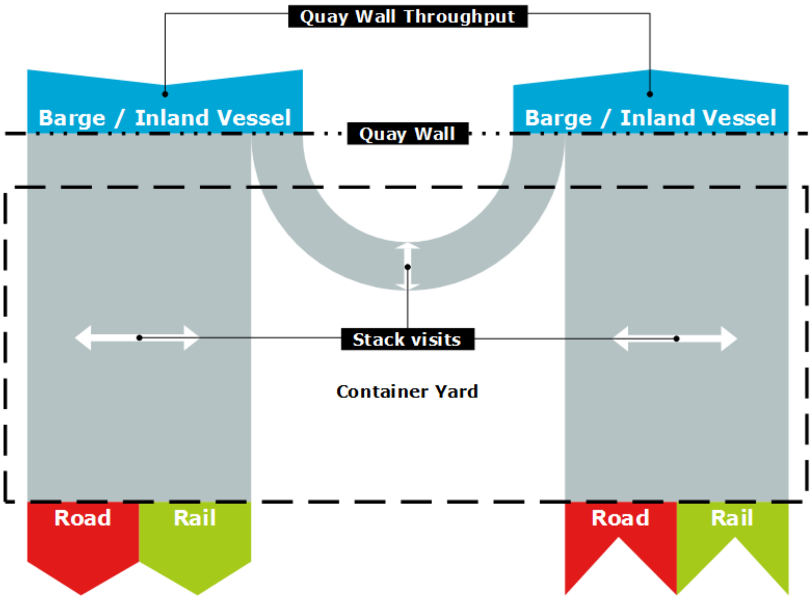


Figure 5.4: Relevant and expected container flows over terminal. (Modified version that excludes the originally present domestic cycle, based on original from Saanen [2004])

5.2. Terminal Equipment and the Stack Yard

The previous section already mentioned some common equipment found at current inland terminals. Currently, roughly three distinctive types of handling equipment perform operations. Figure 5.5 shows a large, rail-mounted gantry crane. This type of crane can, apart from quay operations, be used to maintain the stacks and even to load at the landside transfer side. One driver operates one gliding crane, reducing the need for additional equipment and personnel. Figure 5.5 shows an example of operations for a wide-span gantry crane.

Such a crane is, however, very expensive as Rademaker [2007] has demonstrated.[1] Table 5.1 outlines the operational characteristics and costs that were applicable for this crane type around 2007. The depreciation cost effect of such a crane is, however, very small in terms of the overall cost level. When incorporating the capital cost and R&M cost, these costs become more significant and can be the difference between profit and loss. These costs are discussed in more detail in the next section (5.3). For such a crane, simple restacking operations are relatively expensive. Making use of only one crane also requires efficient stacking, or else the crane has to perform additional movements, slowing the entire terminal down. Breakdowns are extremely costly, because they almost certainly result in delayed or even halted terminal operations. This is not only the case for this type of crane, but for all equipment of which there is only one at the terminal. In the case of a small-scale, automated, and low-cost terminal, breakdowns are critical for the operations. These risk and reliability factors are internalized via the generalized cost approach (GCA).

Summarizing the strengths and weaknesses of the gantry crane provides the following image: this crane type is fast and can efficiently load/unload vessels, trucks, and trains. Additionally, it is a good stacking device that allows for high, compact stacking, which decreases the terminal's required space or increases the terminal's storage capacity. On the other hand, this piece of equipment is expensive and sensitive to failure. Many inland terminals have only one gantry crane, making them dependent on that single crane. In practice, a versatile gantry crane is not enough to efficiently operate an entire terminal. If both the dry and wet quays and the storage facility have to be served by one crane, operations will become slow and inefficient. Most inland terminals do, however, make use of one or more widespread gantry cranes. It is presumable that operations can be most efficient and profitable when using this piece of equipment. The stack and throughput capacity per gantry crane is, however, limited. When the terminal is expected to grow significantly, this type of equipment is difficult to upgrade [Rademaker, 2007].

[1] Although this source dates from 2007, Smid et al. [2016] and Wiegmans and Konings [2015] show similar costs for more recent times.

Figure 5.5: Wide-span gantry crane: real world application and schematic operations overview. [Rademaker, 2007]

Table 5.1: Equipment benchmarks wide-span gantry crane (Base year = 2007). [Rademaker, 2007]

Outreach (maximum)	40 m (up to 16 TEU on deck)
Rail span	35 – 70 m
Back reach	25 m
Lifted load	40 MT
Trolley travel	150 – 180 $^{m}/_{min}$
Hoisting speed	50 - 75 / 100 – 150 $^{m}/_{min}$
Crane travel	45 - 120 $^{m}/_{min}$
Crane productivity	20 - 25 $^{moves}/_{hr}$
Handling capacity per crane per year	50,000 - 100,000 $^{TEU}/_{yr}$
Investment cost	€ 3,500,000 – 4,000,000
Maintenance and repairs costs (annually, % of investment costs)	4 %

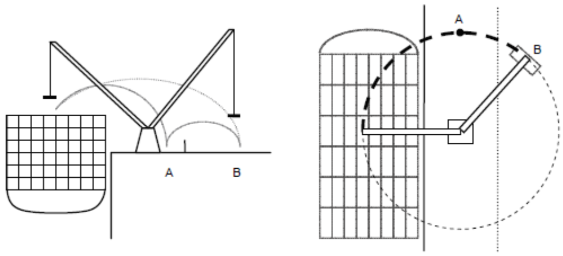
A second piece of equipment that is found at most inland terminals is the reach stacker. The reach stacker can be used for different handling activities across the yard. It can reach out and load smaller vessels, as shown in figure 5.6a. Stacking and (un)loading at the landside entry can also be performed using this type of equipment. Figure 5.6b shows such an operation. The main advantage of this versatile piece of equipment is its manoeuvrability, low cost, and ease of operation. The downside, however, is the need for manoeuvring space, requiring wide paths in between rows of several containers. As indicated in Table 5.6a, the effect is a lower capacity or larger terminal. Looking at Figure 5.6a, it is apparent that the reach stacker has a limited reach. For larger and/or higher vessels, insufficient reach can be a problem. Additionally, the way the vessel is loaded it is very difficult to reach low containers behind a stack of high containers. This handling operation requires additional precautions and thought when (un)loading. The downside of a reach stacker's manoeuvrability and requirement for space is a low handling capacity per hour.

Another option is the use of a harbor crane, which can be either movable or fixed. The downside is that a crane of this type cannot provide an all-in-one solution the way a gantry can. When such a crane is used it can be because annual volumes are too low to afford the more complex gantry cranes, or because items other than containers are to be unloaded. A crane of this type is also capable of loading special goods or even bulk materials. A terminal equipped with a crane of this type often requires the use of additional equipment. Figure 5.7 illustrates some specifics of this crane type. This crane has a lower moves-per-hour capacity than the previously mentioned gantry crane due to its lower hoisting speed in combination with the overall crane layout and movement. In practice, these cranes are fairly rare in inland container terminal applications. The large versions of this crane type have a crane productivity of 15 moves per hour [Rademaker, 2007].

(a) Vessel (un)loading with reach stacker. [Translink, retrieved 12/04/2018]

(b) Truck (un)loading with reach stacker. [Management, retrieved 12/04/2018]

Figure 5.6: Reachstacker operations on both sides of the terminal



(a) Schematic overview of mobile harbour crane operations. [Rademaker, 2007]

Max. lifting capacity	45 t
Max. radius	29 m
Hoisting/lowering max.	44 m/min
Slewing max.	0.70 rpm
Mobility	fixed
Fields of application	Container handling / Bulk handling / General cargo operation

(b) Equipment benchmarks fixed cargo cranes. [Liebherr, retrieved 12/04/2018]

Figure 5.7: Mobile harbour crane specifics

Equipment such as automated stacking cranes, straddle carriers, and automated guided vehicles are not discussed in this thesis. In practice, these are pieces of equipment that perform specialized tasks not required at an inland terminal. Reflecting on the schematic terminal operations provided in figure 5.1, these pieces are used at deep-sea terminals where the stacks are separated from the quay wall operations. Such is not the case at smaller inland terminals. At deep-sea terminals where the volumes are way larger than at inland terminal and the operations are run on a much tighter time schedule, this type of equipment has been adopted in the past decade(s) to let the throughput rate grow. For inland terminals, this equipment is not versatile enough to be used frequently and is therefore often not economically viable. Notice of their strong points is taken, however, and incorporated into further concept designs later on.

5.2.1. Storage Facility

Storage or stacking capability and capacity have now been mentioned a couple of times. Although this area is not a piece of equipment, it is so important that it is also highlighted here. For container storage in its current configuration, there are square meter estimators that are used to estimate the space required for the facility. Depending on the type of storage equipment used, stack area per TEU can be estimated. The difference is caused by the space required for the equipment. Whereas a gantry crane moves over the container stacks and can reach the container from above, there is no need for corridors between the stacks.

Using a reach stacker that rides between the stacks requires paths and room to maneuver. In such a case, for each x amount of stacked rows a path has to be clear, reducing the overall density of stacking. Using ground-based equipment then increases the square meters required per TEU.

Van der Maaten [2002], Rademaker [2007] and Ligteringen and Velsink [2012] have quantified these claims. All of these researchers have mentioned quite similar figures, which are listed in Table 5.2. On average, using a reach stacker requires 2.5 times as much storage area per TEU than the straddle carrier and gantry crane demand, when stacking equally high.

Distilling the true meaning of these numbers, which is useful for the concept design, provides the following trend: relatively low-cost stacking equipment, such as the reach stacker, do come at the cost of significantly more area required for stacking. More expensive equipment, such as the gantry crane, can stack more efficiently, but comes at a higher price. It can therefore be deduced that the combination of container throughput volume and ground price together dictates the choice of which equipment to use. In more crowded areas where land prices are often more expensive, the more dense stacking will be more favorable. In lower priced areas, space comes cheap, making low costs more interesting. Growth perspective also plays a role in forecasting necessary equipment. If the terminal is likely to increase its throughput volume significantly, it might be beneficial to begin with a spacious layout that gets more compact over time.

A new terminal beginning with simple equipment that is only used during the startup phase is not necessarily advantageous. If the simple equipment has to make room for better pieces after a short period, significant cost can be incurred. As a result, it might be better to begin with better equipment than is strictly necessary for the starting phase. This is an important factor to incorporate into the scalability of the concept terminals, since the start-up phase can lead to more losses than the future operations can make up for. Additionally, justifying the investment is an important parameter for the success of the concept.

Table 5.2: Comparison of required stack area per TEU when using different terminal equipment. (modified version of Ligteringen and Velsink [2012])

System	Nominal Stacking height # of containers	Required area (m^2 per TEU)
Chassis	1	50-65
Straddle carrier	2	15-20
	3	10-13
Gantry crane	2	15-20
	3	10-13
	4	7.5-10
	5	6-8
Forklift Truck	2	35-40
Reach stacker	3	25-30

The storage facility is a three-dimensional stacking area, which means that containers can be stacked next to, in front of, and on top of each other. Storing the containers close to each other minimizes the required area for the stack, but it decreases the accessibility of the individual container. This is a tradeoff that has to be made. Whereas the overhead cranes do require little room, equipment such as the reach stacker require room to maneuver. For the concept design, it is not only the storage dimensions that should be kept in mind, but being able to move containers with reasonable ease is also of great importance.

Just as with stowage on board ships, container stacking means that the lower containers can no longer be reached. The accessibility of stacked containers decreases exponentially with the stacking height. This means that the higher the stack is, the more difficult it is to reach the lowest container, and that the accessibility is hampered more by adding a second layer than by adding a fifth, for example [Rademaker, 2007].

Organizing the stack is something of a make-or-break situation. It is either done properly, avoiding most unnecessary movements, or it becomes a disorganized mess. Absolute perfection can hardly ever be achieved because last-minute changes, faults in documents, and human error are difficult to avoid completely.

A commonly used formula for calculating the required storage capacity, expressed in TEU, is provided in Formula 5.1 [Rademaker, 2007]. The storage capacity (C_s) is a function of the stack visits (S), the average dwell time (t_d), and the peak factor (P). Since the scalability of the terminal design is important, there is no such thing as an optimal or universally correct storage number. It is important to be aware of these different influencing factors.

$$C_s = \frac{S * t_d * P}{365} \tag{5.1}$$

$$S = C_q * (1 - 0.5 * \mu) \tag{5.2}$$

The stack visits, measured in TEU per year, can be calculated using Formula 5.2 5.2 [Rademaker, 2007]. It is dependent on the quay handling capacity in TEU per year (C_q) and the transshipment factor (μ). The quay-handling factor is a measure of the annual container throughput across the quay wall. More containers mean more operations at the stacking facility. The transshipment factor reduces the stack visits. If the container does not end up in the stacking facility because it is stored elsewhere or is directly transshipped to another modality, the stack is not used, requiring less stacking slots.

Average dwell time is the average time a container stays in the stack without being taken out again. When many containers are called at the terminal at once, as is often the case in shipping, not all of these containers are retrieved by clients at the same day-part. These containers then stay in the stack for a period ranging from hours to days or even weeks. In deep-sea ports, containers sometimes stay in storage for six months [Van der Rakt, 2002]. In cooperation with Royal HaskoningDHV, Van der Maaten [2002] has proposed the following assumption for inland terminals: an average dwell time of two days for standard full containers and six days for standard empty containers. No spread is provided for these numbers.

Looking at the likelihood of these numbers, the sailing scheme has to be kept in mind. Most containers reserve a spot on the vessel for outgoing cargo, meaning that they are most often brought to the terminal in the days before the departure of the vessel. The same principle applies to incoming containers. Empty containers are often under less time pressure, resulting in them staying at the terminal for longer. It can be more cost efficient to skip a voyage and get a lower price on the next because there is less demand.

Additionally, a choice can be made regarding the dwell time. Either a free regime is incorporated, leading to a large spread in dwell times for boxes passing over the concept terminals, or the duration of stay is limited using a certain progressive tariff setting. This way, the dwell time could be bounded to prevent clouding of the terminal's strong points. The stack area and corresponding equipment can then be made just large enough, and no excessively large and costly equipment has to be bought.

The peak factor is there to ensure sufficiency. When working with averages and designing the optimum for that point, there is only sufficient space for situation lower than and equal as average. There are, however, also periods throughout the year – for instance, in the run up to the holiday season – that more goods are shipped, leading to a temporary peak in container numbers. In practice, the peak factor is the reciprocal of the average desired utilization degree at the terminal. As previously mentioned, the higher containers are stacked, the more moves have to be made. It can therefore be beneficial to run the terminal with stacks that are, on average, three high, with the option of adding a fourth in peak periods. In that case, the peak factor would be 4/3. The average utilization degree is therefore 75%, and the terminal has a 25% excess capacity for peak periods.

The manufacturers provide operational specifications for the equipment used. The handling capacity per hour for a gantry crane is, however, the maximum theoretical productivity it can reach. As a result, Saanen [2004] has distinguished four different productivity categories. If the terminal's equipment is known, its theoretical productivity is known. Incorporating several real-world factors leads to the gross productivity. This could be considered the "true" or real productivity. Equation 5.3 indicates how these four factors are ranked.

- **Technical productivity** is the maximum theoretically achievable productivity by a piece of equipment determined solely by equipment specifications and travel distances. Disturbances, interventions and delays are not taken into account.
- **Operational productivity** is the maximum productivity of a piece of equipment in operational cycle. Operators' skills and external influences such as surface conditions are taken into account.
- **Net productivity** incorporates the interdependence of pieces of equipment for their handling rate. The operational cycle of one piece of equipment is a link in the container handling process and during one operational cycle several interactions with other equipment may occur. The most important interaction is the interchange of containers between, for example, a quay crane and an AGV, but also equipment of the same type interacts as when that same AGV gives way to another AGV. The net productivity is calculated via the total number of productive moves divided by the production time.
- **Gross productivity** of terminal equipment is measured from start to end of vessel handling operations taking all disturbances into account. These disruptions include operator related delays such as crew changes and meal breaks, equipment related disruptions due to refueling and breakdowns, and operational disruptions such as handling hatch covers and bay changes.

$$\text{Gross productivity} < \text{Net productivity} < \text{Operational productivity} < \text{Technical productivity} \tag{5.3}$$

5.3. Handling Costs

The bottom line for most users of any inland terminal is formed by the price in relation to the service they receive. Part of the GCA also works in this setting. Clients' decisions are based not only on the tariff, but also on the frequency of service and additional service. Smid et al. [2016] have conducted research to determine the characteristics of container terminal types and sensitivity of operations under several conditions. Their results have indicated that the size of a terminal defines its sustainable cost level, meaning that larger terminals can charge lower tariffs. Effects of recurring delays and/or extreme weather circumstances in the case of manned terminals lead to increased cost levels in the order or several percent. Substantial subsidies, although risky because they may not be considered reliable in the long run, can decrease the cost level order size tens of percent.

Studies conducted by Smid et al. [2016], Ziel [2017], Van Staalduinen [2014] and Wiegmans and Konings [2015] have not consistently distinguished whether or not costs are box or TEU-specific. Given the fact that the TEU/FEU ratio of 3/5 leads to one box representing 1.67 TEU, it makes a significant difference whether, for instance, 50,000 TEU or boxes are handled. 50,000 TEUs represents 30,000 boxes. At an annual operating cost of €3 million, for example, a 50,000-box terminal has a cost of €60 per box. A 50,000 TEU-terminal (30,000 boxes) sees the cost per box increase to €100. This difference is vital in the determination of whether or not a new handling concept can outperform or compete with existing terminals.

Figure 5.8 illustrates the original curves according to Smid et al. [2016] (base year = 2016), who have proposed that the number of TEUs is equal to the number of containers passing the terminal. A 50,000-TEU terminal would consist of 50,000 boxes, requiring at least 50,000 moves. In reality, a container will, on average, be equal to 1.67 TEU, so by dividing the number of TEU stated by 1.67 S/M/L/XL/XXL (all with the added _box), an annual container throughput of 12/30/75/120/300 thousand is calculated. It can then easily be observed that the cost per container increases significantly. In fact, the costs increase by 66.7% due to the handling volume decreasing by a factor 1.67. The black line in Figure 5.8 marks the difference between the original data on the right side and the corrected values on the left side.

According to Smid et al. [2016], there is no feasible business case for terminals smaller than 50,000 TEU. The resulting cost level is displayed in Figure 5.8. A remark in place here is that this figure displays the cost levels without subsidies. Smid et al. [2016] have mentioned that normal handling tariffs are around €35–€40 per TEU (base year = 2016). The result is that in the long run, terminals with cost levels above €40 per TEU (€66.67 per box) (base year = 2016) cannot exist. It could then be concluded that either the cost estimation by Smid et al. [2016] is off, or subsidies/start-up credits are at play. In the Netherlands, for instance, Van Staalduinen [2014] has found that 19 out of 37 terminals (51.3%) have annual volumes below 50,000 TEU and have been operational for multiple years. The basis for Smid et al. [2016] research is a paper by Wiegmans and Konings [2015]. They do, however, mention a substantial subsidy program from the governments of both the Netherlands and Belgium intended to promote IWT. The costs structure of their terminals is shown in table J.3 in Appendix J.

Ziel [2017] has assumed handling charges slightly higher than the costs mentioned by Smid. He has estimated €40 per container (base year = 2017) for an 85,000-TEU facility and €50 per container for a small, 10,000-TEU terminal. The latter terminal opened in Q3 2016 and is making significant strides in increasing its throughput volume. What is remarkable about Ziel's research is the fact that a container going from ship to stack and afterwards from stack to truck is charged twice the handling rate. This was not the case in the assumptions made by Smid et al. [2016].

Research by Van Van Staalduinen [2014], however, has not demonstrated that, for instance, throughout the Netherlands different sizes of inland terminals are operated ranging between 10,000 TEU and 150,000 TEU in annual throughput. The smaller terminals primarily exist because of reduced competition in their service area. This allows for slightly higher rates. Another factor is the fact that they are situated on cheaper pieces of land in more rural locations. Additionally, some terminals are the property of the same owner or conglomerate, allowing for a higher price than free competition would (i.e., the owner has a local monopoly on IWT container service). Additionally, some of these terminal owner/operators have also internalized the shipping and PPH trucking. This vertical integration makes it possible to offer an all-in-one solution, which can be valued more highly than working with several separate parties. Concepts relying on a dedicated vessel-terminal cooperation will automatically have the possibility to use this chain integration. The main reason for the feasibility of these terminals is, however, their larger distances to ARA ports, leading to a larger gap between the IWT and the long-distance truck haulage alternative.

As a result, the following conclusions can be drawn:

1. Small scale terminals (TEU/year ≤ 20000) have minimal assumable cost of € 1.4 million
2. This leads to handling costs per box of ≈ €117.
3. Increasing size is the only way for currently existing small terminals to lower handling costs.
4. Vertical integration and pursuing a local monopoly can enable higher tariffs.
5. Handling cost per container is equal to the annual operating cost divided by the annual box throughput volume, since terminals do not make distinction between the size and weight of a container.

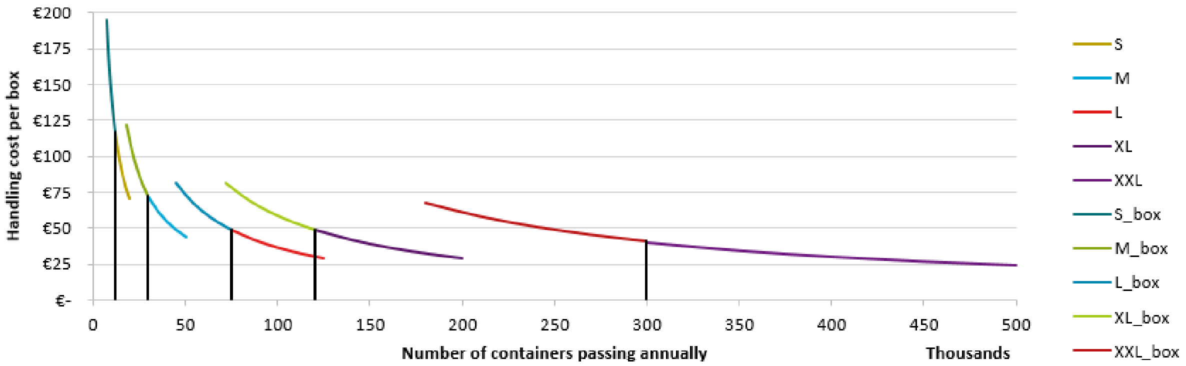


Figure 5.8: Handling costs of five different IWT terminals within the range of 60% to 100% used capacity. Terminal maximum capacities are 20/50/125/200/500 thousand TEU annually for resp. S/M/L/XL/XXL terminals and approx 12/30/75/120/300 thousand TEU for _box terminals. [modified version, original from Smid et al. [2016]]

Table J.3 in Appendix J shows small, small low-profile, and medium terminals. The costs at the bottom of the table indicate that the cost per handling can be lowered between the small and small low-profile terminal (Both 20,000 TEU, base year = 2011). Since it is primarily equipment costs that can be reduced, the effect is between €20 and €10 euro per move roughly. It is apparent, however, that instead of opting for the low-profile option, pursuing the medium size (50,000 TEU for the base year 2011) has a much greater effect. Operating a 50,000-TEU facility on a 20,000 TEU annual throughput, however, is more expensive than operating a 20,000-TEU terminal at full capacity.

When more and/or more expensive equipment is bought, an effect with almost double the influence comes into effect. Depreciation increases, but since a large loan is required, interest also increases rapidly. The opposite of this effect also plays an important role for the concept terminal. Each euro that can be saved results in not only an euro less of depreciation, but also an euro less of interest over a 25-year period.
In conjunction with the work of Wiegmans and Konings [2015], Rademaker [2007], Van Staalduinen [2014], Van der Maaten [2002] and Saanen [2004], the following general estimates are presumed: annual interest is 6% of the total assets, annual R&M of vulnerable equipment should be between 5% and 10% of their new price, and annual quay wall associated costs are €200 per meter, which is between €375 as suggested by Wiegmans and Konings [2015] and €125 as suggested by Smid et al. [2016].

5.3.1. Service Area

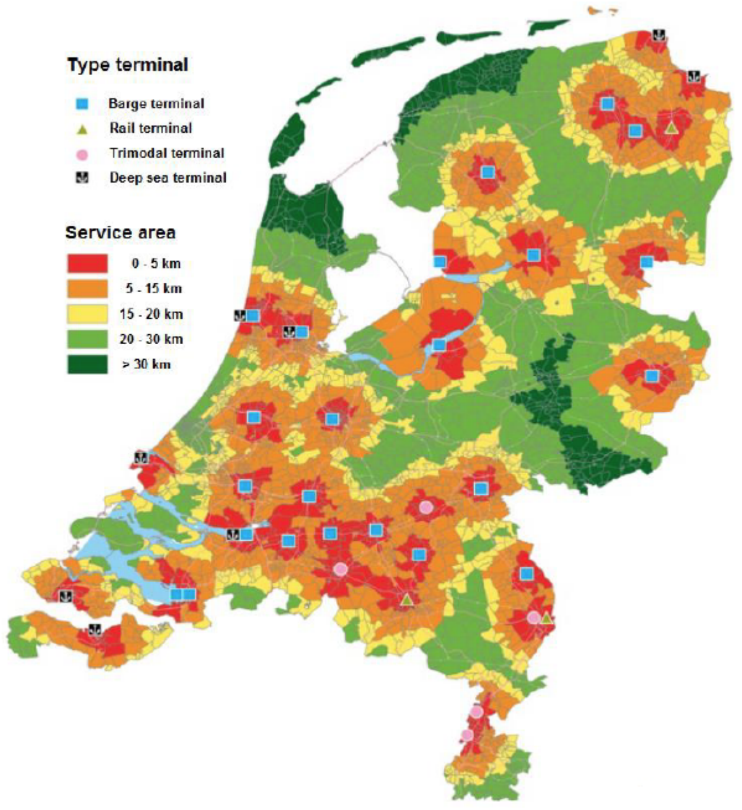
Potential annual throughput volumes are a combination of the service area and the cargo density in that area. As figure 5.9a demonstrates, existing terminals are spread across the country. Clusters of multiple terminals mark more densely populated and/or more industrially active areas for a larger region.

As previously mentioned, a large IWT vessel has the potential to gain substantial EoS that enable handling and PPH. Figure 5.9b demonstrates how the service area theoretically grows with increasing IWT distance share. The competition from direct haulage and other large terminals and/or larger vessels also plays a role in the service area. For example, Ziel [2017] has found that a maximum of 31,000 TEU was potentially present in the Deventer area, but that for all of the potential containers, existing terminals could offer a lower tariff, making them the cheaper option. These current alternatives are also less time-consuming because higher frequency operations are offered. It is therefore important to investigate the competition and their offered transport solutions. Doing so also requires insight into future taxations of external transport costs, as established in Chapter 3.

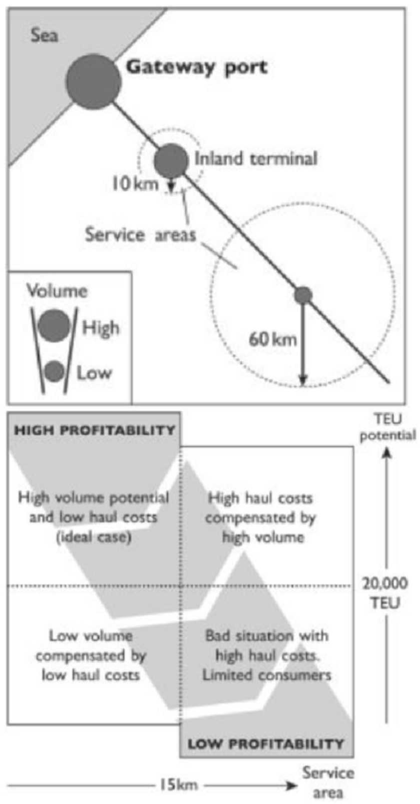
In the case of Ziel [2017], for example, the container terminal Nijmegen (the Netherlands) could offer a substantially lower tariff, even with relatively long PPH up to 70 kilometers. The main contributors are the low IWT tariffs resulting from a very large inland vessel and an L/XL terminal with very low handling rates. If truck haulage is taxed for congestion and/or emissions of exhaust gas in the future, the PPH costs will increase, reducing the profitable boundary of Nijmegen's service area. As a result, more local terminals might gain more feasibility.

The example in Figure 5.9a reveals the good coverage offered by the existing terminals. This does not, however, mean that the inland container terminal market is necessarily fully supplied. The small-scale, low-cost terminal can potentially penetrate the capillaries of the network. As a result, the spread can become even denser. In many places, the service distance to the nearest terminal is at least 20 kilometers. Additionally, terminals can focus on direct transport between larger inland terminals in order to bypass the ARA ports and offer an additional point of connection. The direct linkage of two denser areas that are separated by a decent distance could be a business opportunity worth pursuing when the interchanged container volume becomes significant. Similar to how almost every waterway bounded city or village has a quay for sand and gravel, a future with small container terminals for these communities could be possible. Additionally, outperforming existing inland terminals by offering a better GC alternative will mean that there is always a market to pursue.

While the Netherlands is extremely dense and has a large container terminal (CT) coverage, elsewhere in the Blue Corridor this spread is more open and requires longer PPH. Figures G.4 and G.3a in Appendix G illustrate the container terminal spread of the Blue Corridor as it was in 2011.



(a) Coverage of Inland Terminals in The Netherlands (anno 2013) [Van Staalduinen, 2014]



(b) Framework of terminal profitability in the Netherlands. [Van Staalduinen, 2014]

Figure 5.9: Service area's of inland terminals located in the Netherlands.

The service area for which the terminal is the preferred transport option defines the terminal's annual throughput volume. To handle this amount, a certain service frequency and call size should be offered. Table 5.3 indicates how many TEUs can be handled annually given certain combinations of call size and sailing frequency. A call is the sum of ingoing and outgoing containers. It can be easily seen that, for instance, there are multiple options open for handling 6,000 TEUs. A once-per-week operation using a large vessel with a 60-TEU capacity could be used when the call consists of an even division between incoming and outbound boxes. When using a smaller vessel, the sailing frequency could be increased to three times per week, reducing the time a container potentially has to stay at the terminal.

By using variable tariffs depending on the required service, the terminal and ship operator (in the integrated scenario) can optimize and adjust the required terminal dimensions and the required amount and size of the vessels used, all of which is in favor of the scalable approach.

An ideal situation would be, for instance, when a container client can choose from a variety of options ranging from fast handling and shipment at a higher price to regular operations and shipment. This way, the flow of containers can be evened out, reducing the need for abundant capacity and the requisite high costs. As a result, the use of the terminal equipment and vessels can be maximized, reducing the costs per use. This, in turn, is highly likely to match with the clients desire or transport demand that is diverse.

Table 5.3: Example of resulting annual throughput volume in TEU depending on the call size times the sailing frequency.

Annual throughput		Frequency (calls per week)				
		1	2	3	5	7
Call size (TEU)	20	1000	2000	3000	5000	7000
	40	2000	4000	6000	10000	14000
	60	3000	6000	9000	15000	21000
	80	4000	8000	12000	20000	28000
	100	5000	10000	15000	25000	35000
	120	6000	12000	18000	30000	42000
	140	7000	14000	21000	35000	49000
	160	8000	16000	24000	40000	56000
	180	9000	18000	27000	45000	63000

The price setting of the storage facility is a business in itself. The optimal price point depends on two factors, namely the price elasticity of demand and the alternative solutions. Beginning with the first, price elasticity is a measure of the relation between the price and the desire or use of the service. Figure 5.10 shows three likely scenarios. Beginning with an elasticity equal to 1 means that decreasing the price by 10% leads to an increased demand of 10%. There is therefore a direct relation between the storage cost and demand for storage, and since revenue is price multiplied by quantity, the price point is irrelevant for the revenue.

In the case of inelastic (≤ 1) or hyper-elastic (≥ 1) prices, the price point has greater impact on the quantity. For the inelastic line, the revenue will increase when the price is lowered. The inelastic relation means that decreasing the price by 10% leads to a demand increase of more than 10%. The opposite is true of the hyper-elastic relation it, meaning that increasing the price by 10% leads to a decrease in demand of less than 10%.

This elasticity of demand for container storage is not known, and researching this lies outside of the scope of this thesis. Circumstances per location also make this elasticity vary; therefore, even if a certain correlation were found, it would not certainly be applicable, especially for the wide variety of scenarios in which the terminal could operate.

The other major influencing factor is the presence/competition of alternative transport solutions. If an existing terminal nearby offers transport at a higher rate but with cheaper storage, the overall result could favor that option. In that case, the effect of a price increase would be the termination of containers offered for storage at the scalable container handling concept (SCHC) terminal.

Overall, it could be argued that storage of a container at an inland terminal should be considered a service to attract containers for normal storage periods. Normal storage could be determined to be the average dwell time, potentially with some extra time. If the client wishes to store his/her container for a longer period, this could be sold at an additional tariff or storage premium. Storage premiums are therefore an interesting method of controlling the average and extreme dwell times.

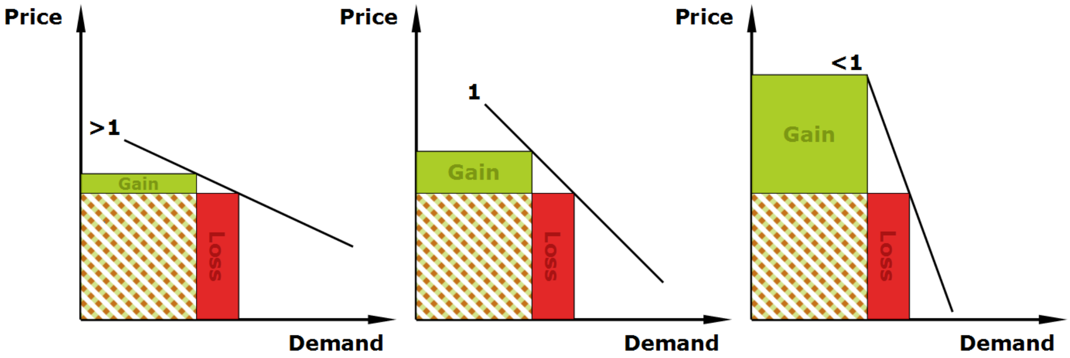


Figure 5.10: Elasticity of demand[source = own work]

5.4. Bottlenecks

There are currently two types of terminal designs. First, there is the waterfront design with moving equipment that can span the entire hold space. In some applications, such as sand and gravel, it is also common to have a central collection point. The vessel then moves parallel to the quay in order to be (un)loaded. From a regulatory point of view, however, there are differences between these two designs. For the movable equipment version, the quay length has to be at least 1.1 times the vessel's length (L) [Rijkswaterstaat, 2017a]. In the case of a moving or shifting vessel, this requirement increases to two times L [Rijkswaterstaat, 2017a]. Even if a stationary layout may be cheaper, it is not necessarily a feasible solution for all applications.

The fact that less-advanced and less expensive equipment can then be used is the main advantage. This is an important consideration, especially for the design of new, to-be-developed terminals. One of the options proposed by Ziel [2017] consists of a cofferdam at the embankment (see Figure 5.11). Such a solution could be considered when a different quay wall layout is thought of and the concept is able to move containers across the ship.

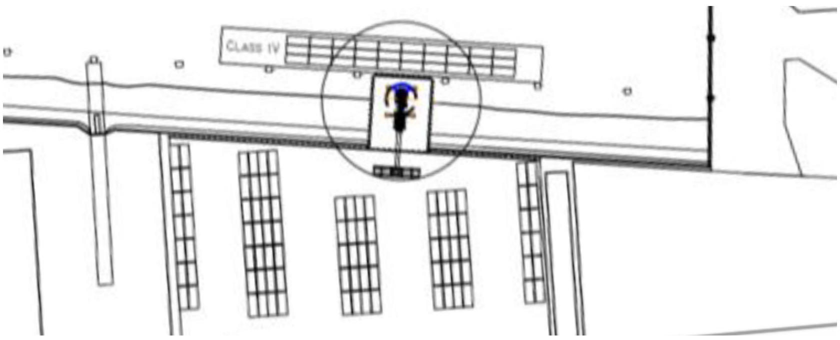


Figure 5.11: Impression of cofferdam at an embankment. [Ziel, 2017]

For inland waterways that are not closely connected to open sea, tides do not play a role. This means that during the berthing no significant change in the water level is expected. Closer to sea, the effects of tide start to come into play, which has to be taken into account for short-distance applications. This effect can be ignored farther away from the ARA ports and/or the shore.

Non-tidal waterways, however, do not have fixed water levels throughout the year, either. They are under the influence of changing conditions upstream. In controlled areas, the change between high and low water is minimized. There are, however, extremes between which the water level can differ by more than a meter and even up to 2 meters in one day. The seasonal change in water levels has to be incorporated into the terminal design later on, as the terminal would otherwise have severely limited operability.

Extreme daily changes are left out of consideration from this point onwards. The concepts should not be designed for 1% of their operational use when it severely impacts the other 99% of their operations.

Apart from the changes due to water level, the ship's draught is also likely to change under (un)loading. These changes are currently not an issue, because loading is done from above. Concepts considering horizontal container movement will have to incorporate changes in the vessel's draught. It is then expected that it will be relatively easy to incorporate regular water level changes and their impact.

The location of the terminal determines the applicable rules. The Dutch waterway administrator, Rijkswaterstaat [2017a], enforces a set of rules regarding inland ports and waterways. They have made a clear distinction between wharves [2] and harbours for inland navigation.

Some of these rules can be taken into consideration. On smaller waterways, for instance, may wharves not reduce the effective waterway's width. When a recess has to be dug to prevent a reduction in the waterway profile, significant costs are incurred for either the private terminal owner, the waterway operator, or the municipality. In any case, these additional costs have a negative impact on the overall project's likelihood for adoption. For the remainder of this research, however, these factors are set aside because no specific site is under review. It is therefore impossible to incorporate these effects accurately.

Quay walls are not necessarily easy to take borders. Figures 5.12a and 5.12b show two common occurrences of the wall in current use. It is apparent that the high quay cannot accept horizontal handling in its current form. For the terminals to be developed, the quay wall layout, consisting of a.o. height and length, is of great influence on the ship design, and vice versa.

(a) Very high quay wall at container terminal Duisport, Duisburg Germany. [Koppen, 2014]

(b) Normal, low quay wall at Oosterhout container terminal, The Netherlands. [Multimodaal Brabant, retrieved 12/04/2018]

Figure 5.12: Difference of quay wall height at different terminals.

The principle of intermodal transport rests on the loading and unloading of containers without the need to alter the container's configuration. Currently, the top corner castings are used during (un)loading containers from inland container vessels. Given the structure of the containers, they can be handled at the corner castings and at the forklift pockets; however, when the containers are stacked inside the vessel, these pockets cannot be reached.

An unloaded container can be put directly on a trailer, in the stack, or just on the ground near the quay wall. Process-wise, the containers are moved both vertically and horizontally when (un)loading. Whereas the horizontal movement is desired and required to cross the terminals perimeter, the vertical movement is solely necessary for the current method of (un)loading, and no alternative is currently present. Making a comparison with ferry (un)loading, trucks roll aboard instead of being lifted one by one. For inland container transport, such rolling solutions might also be a feasible option. This way the need for large and expensive cranes is removed, potentially reducing the startup costs of new terminals and increasing the simplicity of operations.

[2] Wharves are parallel moorings situated alongside the waterway itself. Additional information can be found in Appendix K.

In cases where the ship navigates between two points only, all containers will usually leave the vessel at both ends. When a round trip is made consisting of more than two locations, it may be assumed that not all of the containers leave the vessel at each facility. This means that cargo handling and the order of (un)loading becomes even more important. Stacking containers means that in order to reach the lowest container, all of the containers that are on top have to be taken off first. With the help of stacking software, the unnecessary movement of containers is minimized when done properly. For concepts that use different (un)loading procedures, such as sliding horizontally, thought has to be put in solving these challenges.

Rademaker [2007] has analyzed the most likely/common causes for delays in the quay crane production cycle. Table 5.4 provides a reduced version of these possible delays for inland terminal quay cranes. The deep-sea terminal-specific delays have been removed. Improving the production cycle for quay cranes can primarily be done by reducing the number of operations in the cycle or by increasing the number of containers moved per cycle by using twin lifting or pursuing the one-in, one-out principle. Incorporating cell guides removes twistlock handling and potentially reduces sway and vessel movement influence.

Table 5.4: Possible delays for the production cycle of a quay crane. (Reduced version for inland terminal quay cranes, based on Rademaker [2007])

Operation	Possible delay
connect to container	vessel movement
	equipment sway
hoisting and transfer to quay	waiting for other crane
twistlock handling	no handlers
	no twistlocks
handover	equipment sway
empty travel to next container	waiting for other crane
	crane/vessel repositioning (bay change)

Operations at a terminal's landside gate(s) are almost as important as those at the quay wall. The operations at this end are often less scheduled, since waiting time of a truck is marginal compared to that of inland vessels. Focusing on trucks for the present, a clear distinction can be made between. There are trucks that come and take containers JIT, and there are those that come when it suits them best. For the JIT trucks, the operations should be more streamlined, because they are expected to get in and out quickly. For the other trucks, some waiting time is more understandable because it is unclear when they might come and what container they are coming to pick up.

Working in close cooperation with the shore-handling equipment, the there mentioned case could become reality. In the simplistic terminal concepts, there should also be some focus on the gate process. Since time is money, trucks waiting unnecessarily costs haulage companies money. This also reduces the attractiveness of the newbuild terminal.

In the current situation, truckers often have to come to the desk with a pile of paperwork to demanding their container. Deep-sea ports are a step ahead and already use license plate-scanning software, after which the truck is allowed in and the terminal's computers know what container is being picked up Rademaker [2007]. The latest automation attempts at inland terminals have centered on adopting these types of new technology.

Whereas the inland waterway terminal should be located along a navigable waterway, the same is true for the landside, which should have good connections to the road network and, when possible, even the rail network. Reflecting back on the background of this research, the terminal should reduce the nuisance caused by road freight transport. It would be very disadvantageous if the supply and discharge led to hindrances. Having large trucks frequently passing over small country side roads or near city centers are examples of such undesirability.

5.5. Intermediate Conclusions Chapter 5

Based on the cost and tariff level estimations by Wiegmans and Konings [2015] and Smid et al. [2016], a terminal with market average service in the current market has a "by market formed" tariff approaching €50 per TEU (€83.33 per container) (base year = 2016). Theoretical costs of ≤ 50,000-TEU terminals are, however, higher than current operational tariffs. Previous subsidies and stimulating programs have lowered the costs levels of these smaller terminals. In theory, this means that small to medium-sized inland terminals cannot exist, but that with subsidies, a viable business opportunity can be pursued. For the to-be-developed concepts, the subsidies should be included when a reasonable likely scenario is in play. Subsidies can lower the cost levels of terminals, and the GCA and CBA can be drivers for policy makers to create these subsidies. Especially in the current political climate, the CBA is an excellent assessment tool for finding the public gain for the project. When the public gain is larger than the minimum required subsidy, a subsidy can be considered a profitable investment.

Many of the current terminal owners/operators make use of vertical integration and inter-organizational operational agreements. This can especially be a business opportunity to pursue. With the concept vessel (SCCC) and concept terminal (SCHC), two of the three intermodal chain parts can be vertically integrated.

Different researchers have approached how to define the cost level of a terminal differently. Some have divided total annual cost by the total number of TEUs the terminal handles annually. It is, however, common practice to charge the client a tariff per move, irrespective of size and loading condition, the result being that for ease of comparison it is best to also calculate cost per box (irrespective of size and loading condition).

Applying this method to the tariffs in use with the assumed 1.67 FEU/TEU factor, it is apparent that a box represents 1.67 TEU. The €50 per TEU is then translated to €83.33 per box (base year = 2016). This is the market-accepted handling tariff according to Wiegmans and Konings [2015] and Smid et al. [2016].

For a sustainable business operation, the regular costs should lie below this tariff. When additional services are provided the accepted tariff will increase, allowing for more costs and/or profit. These numbers are used as reference for the feasibility study, but at the same time they cannot be considered binding. The specific market the concept(s) will operate in determines the market-allowed/determined handling tariff. This tariff then puts a rough limit on the cost level. Service, throughput, the market, and the business strategy together determine what costs and tariffs will eventually be charged.

One of the primary cost elements is the land area and quay-bounded cost. The presence of a competitive container terminal with corresponding competitive sailing offered will increase the attractiveness of the location, resulting in a value increase in the adjacent land. Part of this could be used to subsidize, thereby offering the terminal land to the future terminal owner at a lower cost. This lowers costs, which in turn reduces the required handling tariff.

Investment costs do not only lead to significant depreciation, but they also result in high capital costs due to interest payments. A subsidy or interest-free loan could reduce the capital cost significantly, increasing the likelihood of adoption. The basis for this subsidy could be the reduced EC of IWT, handling, and PPH compared to the current long-distance hauling alternative.

When, *grosso modo*, it is assumed that labor, equipment, and capital cost are equal, the following decision has to be made. When lower labor costs are pursued (e.g., a 10% reduction), more expensive equipment is required. For every percentage point of increased equipment cost, an additional percentage point of interest is incurred. The result is that the equipment cost may rise by a maximum of 5%. In that case, the overall gain is still zero. To reduce the costs of labor, the tradeoff with respect to additional investments in equipment is a delicate one.

Operations and their corresponding costs are a result of the handling capacity of equipment. For the wide-span gantry crane, the larger the crane is, the lower its handling capacity becomes. This is the result of the longer distances the trolley has to travel for operations. In the case of separate (un)loading and stacking, the quay crane can have a relatively high number of moves per hour compared to the gantry crane. These operations come with a cost, because the need for additional equipment that can perform the stacking arises.

Additionally, it should be noted that there are certain non-linearities in the decision-making process. For example, if simpler equipment is used at a quarter of the cost of a gantry crane, *ceteris paribus*, the cost is reduced by 75%. In reality, *ceteris paribus* cannot be achieved, resulting in influences on the entire terminal process and resulting costs. For instance, Stack 4 has to become Stack 2, requiring double the area, which requires additional rails for the crane to run on. Increased distances will result in decreased handling speed, lowering the capacity per hour, etc. It should therefore be kept in mind that changing even a small piece of the puzzle can lead to a variety of changes in the overall process. The impact then becomes far more complex than initially estimated.

Given the equipment cost factor share of 23%, an 18% equipment cost decrease is achieved. This simpler equipment can, however, stack 2.5 times less densely. This is the difference between the gantry crane and the reach stacker. The stacking area, and thereby the terminal, then has to be double the size. The area cost (9% cost share) would then increase by 9%.

The net result is therefore an 18% decrease and a 9% increase. Effectively, based on this simplified example, his choice would lead to a cost reduction of 9%. In practice, more personnel, higher R&M, and additional fuel are required. This example should indicate, however, that there is no such thing as an indifferent terminal design for which the equipment used does not influence the terminal costs.

The attractiveness of the terminal is not just cost-based. Factors such as frequency, incorporated storage, and ease of use also play an important role. The result of advantages and disadvantages should be positive to be able to speak about a change to pursue.

6 Current Market Transport Alternatives

The current market analyses have been made in order to gain understanding of the environment in which future concepts will have to operate. Chapter 2 contained the transport drivers and provided understanding of some crucial variables. Modes of interest were discussed in Chapter 3. Competition under review for to-be-developed concepts consists of CEMT Va inland vessels and truck haulage. Sections 6.1 and 6.2 contain the costs of these competitors. Chapter 4 discussed the cargo under consideration. The costs of using the containers and the time costs associated with loss of business opportunities were appointed. These costs are also incorporated in this chapter. Handling at inland terminals was the subject of Chapter 5. The costs required to enable intermodal transport using the CEMT Va alternative are also incorporated.

The results are briefly accessed in Sections 6.1 and 6.2, both of which reveal the individual parts of the GC per alternative. The results are listed in Subsections 6.1.5 and 6.2.5.

6.1. Competition from an Existing IWT Solution

Throughout this thesis it has been demonstrated that the SCCC and SCHC tandem should focus on outperforming truck haulage. These hinterland-penetrating truck services are not dedicated to direct, unimodal ARA transport. Current long-distance container transport is performed a.o. CEMT ≥ Va IWT, meaning vessels with lengths of 110+ meters and breadths of 11.40+ meters. These ships can carry upwards of 200 TEUs per trip and are often operated fully continuously (Scheme B), allowing them to offer competitive (low-cost) long-distance container transport. For these large vessels, operating schemes have been divided at 71.4% operating fully continuously *"B"* and 28.6% following *"A2"* following a market study in 2014 [Van Kester, 2014a]. The average operating hours per workday are therefore 22.2 hours. In 2015, a large container vessel sailed an average of 4,041 hours [Van der Meulen and Van der Geest, 2016]. Together with the working hours per day, this leads to an average of 182 days of sailing per year. Assuming one day of (un)loading activity per three days of sailing, these vessels are active for approximately 250 days per year. For base year 2015, the average costs of this class were €1.05 million. With increased labour costs and a higher oil price, the current annual costs are estimated at €1.2 million. Appendix L.2 shows an oil price of ≈ $45–50 per barrel, whereas current 2018 oil prices are nearing $75 per barrel [Platts Bunkerworld, 2018]. At 250 operational days, the assumed daily rate for a large container vessel is €4,800 (2018).

$$\text{Average working hours per operational day} = 70\% \cdot 24h + 30\% \cdot 18h = 22.2h$$

6.1.1. CEMT Va out-of-pocket Transport Cost

Table 6.1 details the resulting OOP transport cost for the large container vessel. The rows with 100% loading degree are incorporated to show the minimum possible cost level. In reality, however, these vessels have loading degrees lower than 100%. With signs of overcapacity at the large waterways [Al Enezy et al., 2017], the assumed realistic degree is 75%. In general, a FEU box takes the place of 2 TEU containers, thus creating a double cost. The average costs are listed for ease of comparison later on.

Container-handling costs were discussed in Chapter 5. At large inland terminals, costs are as low as €40 per container. Pre-haulage and post-haulage is estimated at €53.50 per hour and €0.25/0.40 per km for empty respectively loaded condition (both calculated using 2018 as the base year). Table 6.2 reveals the resulting cost for unidirectional PPH distances ranging from 50 km to 200 km.

Since the average detour factor (a measure for the excess distance IWT has to cover due to meandering waterways) was found to be 1.2 , the sailing distances are calculated as truck-equivalent. A 200 km truck haulage is equivalent to 240 IWT kilometers. Table 6.3 lists the IWT distances. From this point forward, the tables will only contain truck-equivalent distances for ease of comparison. Resulting OOP transport costs are provided in Table 6.3.

Table 6.1: Out-of-pocket transport costs for CEMT Va container vessel (base year = 2018)

Sailing distance		240km	480km	720km	960km	1200km
TEU Capacity	100% (208 TEU)	€ 69.23	€ 103.85	€ 138.46	€ 173.08	€ 207.69
	75% (156 TEU)	€ 92.31	€ 138.46	€ 184.62	€ 230.77	€ 276.92
FEU Capacity	100% (104 FEU)	€ 138.46	€ 207.69	€ 276.92	€ 346.15	€ 415.38
	75% (78 FEU)	€ 184.62	€ 276.92	€ 369.23	€ 461.54	€ 553.85
Average	100%	€ 117.69	€ 176.54	€ 235.38	€ 294.23	€ 353.08
FEU/TEU = 70/30	75%	€ 156.92	€ 235.38	€ 313.85	€ 392.31	€ 470.77

Table 6.2: Out-of-pocket transport cost for PPH part (base year = 2018)

Distance	50km	100km	150km	200km
PPH cost	€217.13	€354.00	€517.63	€627.75

Table 6.3: Out-of-pocket transport cost for large container vessel alternative (base year = 2018)

(a) Cost per 20ft container

	Sailing distance				
PPH Distance	200km	400km	600km	800km	1000km
50km	€ 369.43	€ 415.59	€ 461.74	€ 507.89	€ 554.05
100km	€ 506.31	€ 552.46	€ 598.62	€ 644.77	€ 690.92
150km	€ 669.93	€ 716.09	€ 762.24	€ 808.39	€ 854.55
200km	€ 780.06	€ 826.21	€ 872.37	€ 918.52	€ 964.67

(b) Cost per 40ft, 40ft HC or 45ft HC container

	Sailing distance				
PPH Distance	200km	400km	600km	800km	1000km
50 km	€461.74	€554.05	€646.36	€738.66	€830.97
100 km	€598.62	€690.92	€783.23	€875.54	€967.85
150 km	€762.24	€854.55	€946.86	€1,039.16	€1,131.47
200 km	€872.37	€964.67	€1,026.98	€1,149.29	€1,241.60

6.1.2. Time-Bound Cost

To complete the GC alternative of the currently offered IWT container transport, the time costs are included. Section 4.2 contained multiple values for the time cost of containers. Subsection 4.2.1 discussed the daily rent cost. A TEU costs €2.39 per day. The other containers range between €3.42 and €4.60 per day. The total weighted average used for ease of computation and comparison is €4.00 per day. In the least complex calculation, it is assumed that the time between loading at the ARA terminal(s) and unloading at the client location is the only period of interest. Dwell times at the ARA and IT, sailing time, and PPH time together determine the duration of hire.

Subsection 4.2.2 discussed the time value of the goods inside the container. Again averaging the containers' time value, the weighted average across size and origin/destination is €9.00 per day. For PPH, the time-bound costs are calculated per quarter day to allow for some realistic distinction between short and long PPH. The result is that 50 km & 100 km have PPH time costs of €8.50, and 150 km & 200 km add up to €10.75 for a TEU container. The FEUs and 45-foot containers have double those time-bound costs.

Current transport involves high frequencies, especially since multiple competitors each offer different services. As a result, the following assumptions and corresponding values are proposed. 6.4a shows two scenarios and their duration. Table 6.4b shows the time-based cost of using a container for the current CEMT Va transport solution.

Table 6.4: Hire days and cost between origin and destination for two scenarios per container.

(a) Transport duration at each individual process step

Scenario	Terminals		Sailing Distance (km)			Delivery	Total Duration
	ARA	IT	0-350	351-700	701 - 1000	PPH	Sum
Realistic	1	0	1	2	3	1	1 + 1/2/3
Pessimistic	3	1	1	2	3	1	4 + 1/2/3

(b) Time cost per container for current CEMT Va container service

Scenario	Period	Hire Cost	Time Value	Time Cost
Realistic	1 + 1/2/3	€4.00 + 1/2/3 · €4.00	€9.00 + 1/2/3 · €9.00	€13.00 + 1/2/3 · €13.00
Pessimistic	4 + 1/2/3	€16.00 + 1/2/3 · €4.00	€36.00 + 1/2/3 · €9.00	€52.00 + 1/2/3 · €13.00

6.1.3. Risk and Reliability Cost

The final part of the GCA consists of the incorporation, and thereby valuation, of risk and reliability. In short, it can be concluded that risk is reliant on the water level condition on the river. During periods of great drought, water levels drop, resulting in a temporary loss of capacity for ships. Transport contracts include predetermined surcharges for these periods. From ARA tot Kaub (GER) (≈ 450 km), an average charge of €0.38-€0.50 per TEU per kilometer is industry average (base year = 2014) [DG MOVE, 2014]. From ARA tot Duisburg (GER) (≈ 225 km), an average charge of €0.65–€1.25 per TEU per kilometer is industry average (base year = 2014) [DG MOVE, 2014]. Averaging these charges and updating them to 2018 levels, it is assumed that a surcharge of €0.70 per TEU per kilometer is contractually determined. When it is assumed that these charges are active 10% of the time (five weeks per year), an average risk factor of €0.07 per TEU per kilometer is applicable.

The reliability of the operation primarily focuses on congestion in the ARA ports. This can add up to multiple days of delay. For this time, the time cost of the cargo and the vessel rate together should be multiplied by the number of days to find the additional cost. Van der Meulen and Van der Geest [2016] have calculated an industry average hour cost of €259.07 (base year = 2015). The results of delays include higher fuel costs to make up for lost time and lost business opportunities for the vessel as a whole. It is assumed to be covered by the average hourly cost. Similar to the kilometer-based cost in Subsection 6.1.1, updating these to 2018 involves an assumed hourly cost of €300. When the CEMT Va does one call per week for 52 weeks during which it gets delayed for one day every four weeks, 13 times times €4,800 is incurred per year. Averaging this over 52 calls results in a total of €1,200 per round trip. At 208 TEU (100% cap.), a charge of €5.77 per TEU is applied. At 75% capacity (156 TEU), the charge is €7.69 per TEU. When the vessel has multiple calls per week it will also encounter more congestion and congestion-free calls, leaving the charge equal.

6.1.4. External cost

Similar to the approach used in Subsection 7.5.5, the ECs for the CEMT Va are calculated at an assumed operational displacement of 2,500 tons, 15 km/h average sailing speed, and 75% average engine load.

Marginal air pollution is €3.25 per kilometer, climate change is €4.60 per kilometer, and well-to-tank is €0.01 per kilometer. Following the method of DG MOVE [2014], altogether the ECs are €7.87 per kilometer.

Accurate ECs for the current terminals are difficult to incorporate. These costs are therefore assumed to be €10 per TEU. In case these would be left out a certain error is introduced. An assumption would at least incorporate part of the ECs of terminal equipment.

Pre-haulage and post-haulage ECs are calculated with the same tool used to determine the PPH external cost for the SCCC alternative. Table 6.5 shows these values.

Table 6.5: External cost PPH for the CEMT Va transport alternative

PPH Distance	50 km	100 km	150 km	200 km
External Cost	€243.43	€414.28	€585.13	€755.97

6.1.5. Generalized Cost of CEMT Va container service

Adding all the generalized cost (GC) factors together leads to the GC of transport for this container transport chain. Appendix M contains all of the underlying values. Figure 6.1a contains a graph showing the GC when EC is excluded. It is rapidly apparent that the effect of additional PPH outweighs the additional sailing distance effect.

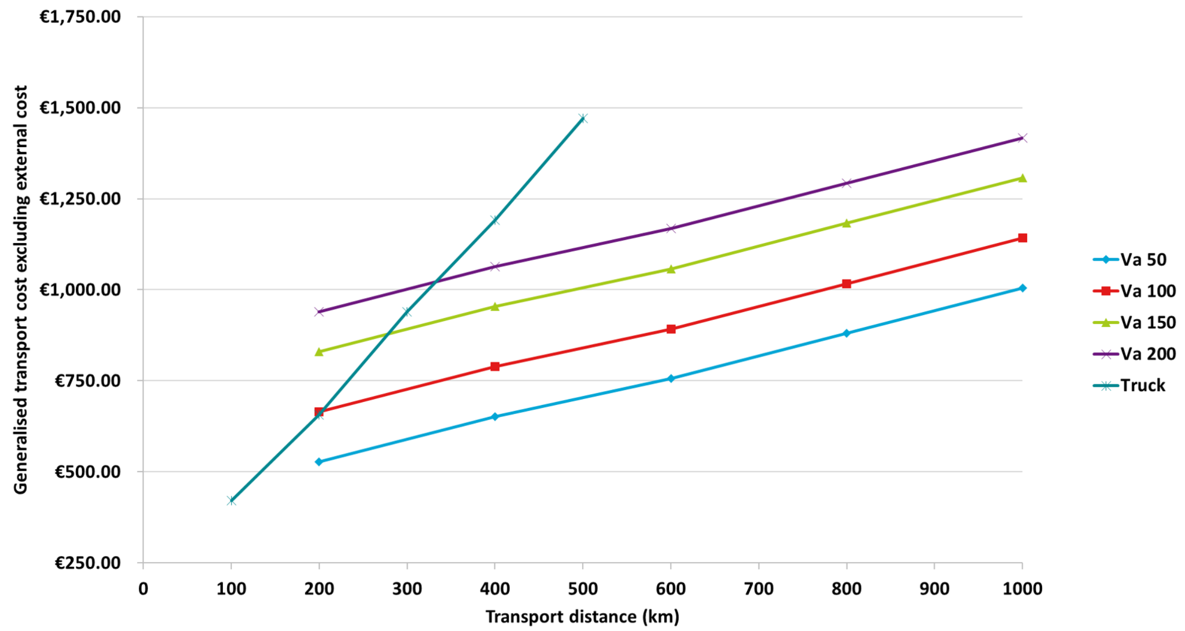
Whereas Figure 6.1a contains the generalized transport cost for an average container, which is the equivalent of 1.67 TEU, substantial differences between a TEU and a FEU/45-foot container do exist. Due to the double slot requirement aboard and the corresponding double cost for the main leg of the transport, costs for the CEMT Va alternative are higher for a FEU/45-foot container than for a TEU. Appendix M shows four figures (M.1a till M.2b) with this effect.

At a truck distance of 200 km, for instance, the CEMT Va alternative has lower costs until ≈ 130 km PPH in the case of a TEU. For a FEU, the truck alternative has costs equal to ≈ 90 km PPH. The case of Chapter 10 will also discuss the effect. A PPH coverage of approximately 105km can on average be reached.

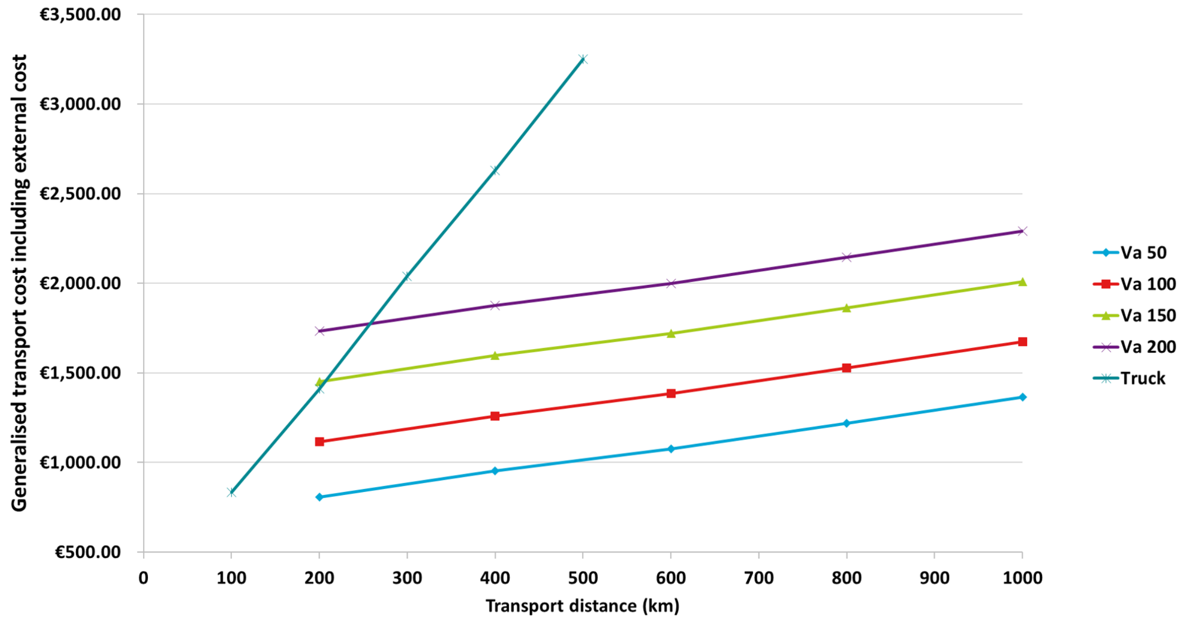
At for instance 200km truck distance the CEMT Va alternative has lower costs till ≈ 130km PPH in case of a TEU (figure M.1a). For a FEU the truck alternative has costs equal to ≈ 90km PPH (figure M.2a). On average as figure 6.1a shows can approximately 105km be covered by PPH for the same cost.

Figure 6.1b illustrates the full GC including the EC valuation. This figure demonstrates that increasing the sailing distance from for example 200 km to 8000 km has a similar effect as increasing the PPH distance by 50 km. For this specific case and under this set of constraints, it can be concluded that the GC for the sailing portion is very low compared to the effect of additional PPH.

Incorporating the external effects shifts these break-even points substantially in favor of the CEMT Va alternative. This is in keeping with the author's expectations, since Chapter 3 explained that IWT was relatively less polluting than truck haulage. For the average case illustrated in Figure 6.1b, the incorporation of external effects allows for ≈ 50 kilometers of additional PPH at a 200-km sailing distance. At a 400-km sailing distance this effect is even greater, allowing upwards of 100 km of additional PPH (240km vs. 130km). Figure 6.1a and 6.1b already incorporate the truck haulage alternative, which is discussed in the next section.



(a) Generalised cost of transport excluding external cost for an average container.



(b) Generalised cost of transport including external cost for an average container.

Figure 6.1: Generalised cost for currently offered container transport by CEMT Va vessel, existing terminal and pre and/or post haulage.

6.2. Competition from Long-Distance Truck Haulage

As mentioned numerous times throughout this thesis, truck haulage lead to problems such as congestion and pollution. For many containers, however, it is still the preferred mode of transport. As a result, the SCCC and SCHC tandem should primarily focus on outperforming this transport performance.

The following assumptions are made to represent truck haulage competition. Section 3.2 demonstrated that truck haulage is primarily competitive in short to medium distances. The range of interest for trucks is therefore set at 100 km to 500 km, with a 100 km interval. During the construction of the graphs, the author quickly found that at unimodal distances greater than 500 km the truck alternative becomes far more expensive than the IWT alternative. Containers being transported by truck over these distances are either special (most likely containing expensive goods) or traveling to a region inaccessible by ship, the result being that these will never be making the mode shift towards IWT.

Trucking distances are divided into two categories: urban and metro. The urban share is fixed at 50 km per unidirectional trip. The remainder is most likely ridden on highways and large rural roads between the metropolises and regiopolises within the Blue Corridor. This division of shares is important for the time-bound and external costs, since speed and external effect monetization are different in both areas.

The primary assumption is the fact that a truck operator will base its cost on a round trip. There is currently no interest in the actual operational tariffs and margins/profits. What this round trip assumptions means is that when a truck is expected to transport a container 200 km, for example, the truck will drive back empty for 200 km. These empty return costs are also charged to the client. [1]

6.2.1. Truck out-of-pocket Transport Cost

The costs of truck haulage were discussed in Subsection 3.2.2. For long-distance truck haulage (≥ 200 km), the hourly rate was determined to be €57.75. The kilometer rate is €0.20/€0.33 for empty/loaded kilometers travelled, respectively. For distances ≤ 200 km, the PPH rates are used. While shipping is a business of days, fast road haulage operations usually take several hours. The resulting OOP costs are listed below in Table 6.6.

Table 6.6: Out-of-pocket transport cost for truck haulage.

Distance	Share		Roundtrip time		Cost
Single side	Urban	Metro	Ride	Process	Sum
100 km	50 km	50 km	3.5 h	3.0 h	€380.75
200 km	50 km	150 km	6.5 h	3.0 h	€616.65
300 km	50 km	250 km	10.5 h	3.0 h	€896.10
400 km	50 km	350 km	14.0 h	3.0 h	€1146.68
500 km	50 km	450 km	18.0 h	3.0 h	€1426.13

6.2.2. Time-Bound Cost

Including 15 minutes of rest for every two hours of driving, all ride times are significantly less than 24 hours. As a result, it is assumed that the time-bound costs are limited to one day. The container hire rate of €4.00 and the time value for loss of business opportunity of €9.00 together bring the time-bound cost of long-distance truck haulage to €13.00 per round trip. To amplify the strength of truck haulage, the costs are calculated per quarter of a day.

Table 6.7: Time bounded cost for truck haulage.

Single trip distance	Single trip duration	Hire Cost	Time Value	Total time bounded cost
100 km	3.5 h	€4.00	€2.25	€6.25
200 km	5.0 h	€4.00	€2.25	€6.25
300 km	7.0 h	€4.00	€4.50	€8.50
400 km	9.0 h	€4.00	€4.50	€8.50
500 km	11.0 h	€4.00	€4.50	€8.50

[1] In practise this is where trucking companies make there true profits. They will try and arrange return cargo for which they can offer the same of lower rate. Result being that at a, for both client, interesting rate goods are transported. The trucking company does not ride empty yet receives double compensation for empty kilometres. This compensation is than pure profit.

6.2.3. Risk and Reliability Cost

Whereas IWT uses high water charges, such measures are not applicable to truck haulage. Congestion charges for delays during transport are hardly ever put into place, primarily because of the great amount of competition within the trucking market.

Given the congestion problem in the ARA ports, it is, however, likely that during contracting agreements an ARA congestion penalty will be agreed upon. A study from Barber and Grobar [2001] has demonstrated that 40% of trucks wait more than two hours at the ports of Los Angeles and Long Beach. Although this study is dated, it does demonstrate the effect and significance of congestion. Using appropriate appointment software can reduce the average waiting times significantly [Zhang et al., 2018]. Zhang et al. [2018] have discovered average waiting times of less than 30 minutes for trucks at deep-sea terminals; however, they have also mentioned that more and more ports financially discourage their most busy (i.e., preferred by truckers) timeslots and encourage earlier and later operations.

The result is a general assumption that one must incorporate an additional half hour (á €30.00) per round trip. One highly likely scenario is that once every two calls an additional hour of congestion is faced, justifying the aforementioned assumption.

6.2.4. External Cost

External cost calculations are based on the value discussed in more detail in Subsection 3.2.3. Table 6.8 lists the resulting EC valuations. The values for 100 km and 200 km differ from those in table 6.5 because of a difference in trip time. For example, waiting time for collection at an ARA port is different from that at a small-scale inland terminal.

Table 6.8: External cost for long distance truck haulage.

Truck haulage distance	100 km	200 km	300 km	400 km	500 km
External Cost	€414.28	€755.97	€1097.67	€1439.36	€1781.06

6.2.5. Generalized Cost of Truck Container Service

The results of the past subsections are now brought together to form the GC of existing truck container service. Table 6.9 lists the resulting values. It is apparent that the ECs are roughly equal to the o.o.p. cost at low distances. At greater distances, the ECs become the majority of the GCs. At 100 km, the EC doubles the total transport cost. For 500 km, the ECs increase the cost of transport by 121.75%.

Comparing the GC – both with and without EC – of truck to the CEMT Va alternative reveals that the truck is already an expensive transport solution at short distances. Since the value of time is not that high (in many cases, the goods have been at sea for weeks), the strength of truck haulage, which is speed, is not of equal value to other aspects.

Consider an example where the origin and the destination are separated by 400 road kilometers. The GC (excluding EC) is ≈ €1,200. The CEMT Va alternative, which involves sailing for 400 km with 50 km of additional PPH, has a GC of ≈ €800. If a client prefers/requires/demands it, the difference (€1,200 - €800 = €400) could be fully written down to the client's own valuation of time. In practice, such a decision will only be made when the contents of the box are desperately needed or when the value is far greater than the transport cost; however, these are extremes. In this example, the majority of the container owners making the choice between the IWT and truck alternatives will select the CEMT Va option. In this example, the truck should be the preferred option of transport when the required PPH distance surpasses ≈ 130 km. Remember, however, that although the ship sails 400 truck equivalent kilometers, in reality it will sail approximately 480 km. The unimodal 400 km than corresponds to 480 km plus 130 km adds up to 610 km, which is more than 50% additional distance.

Table 6.9: The generalised cost of Truck Haulage. GC (excl.) excludes the EC in the total and (incl.) includes them.

Distance	100km	200km	300km	400km	500km
OOP	€ 380.75	€ 616.65	€ 896.10	€ 1,146.68	€1,426.13
Time	€ 6.25	€ 6.25	€ 8.50	€ 8.50	€ 8.50
R&R	€ 30.00	€ 30.00	€ 30.00	€ 30.00	€ 30.00
EC	€ 414.28	€ 755.97	€ 1,097.67	€ 1,439.36	€ 1,781.06
GC (excl.)	€ 417.00	€ 652.90	€ 934.60	€ 1,185.18	€ 1,464.63
GC (incl.)	€ 831.28	€ 1,408.87	€ 2,032.27	€ 2,624.54	€ 3,245.68

III

Construction of Concepts

Part III

If shipping has to become competitive in comparison to land transport, fundamental innovation in the ship-terminal system of unitloads has to take place

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Wijnolst, 1993

7

Scalable Container Carrier Concept

The cover image shows a dedicated container vessel, meaning that it was build with the primary intention of transporting containers; however, this is not the case for most small vessels such as the Penichè, the Dortmund-Ems vessel, and the Rhine-Herne ship. Their cargo holds are designed for bulk and/or general cargo. Having the largest possible hold space is then beneficial, since this dictates the amount of cargo the ship can transport. In most cases, the vessel dimensions are maximized for the vessel's CEMT class, which is primarily based on lock dimensions.

Since the concept introduced in this thesis focuses on a revolutionary handling design, it must also examine the ship's general design. To clarify, consider an example where the width of a container is 8 feet or 2.44 meters, which is rounded in the design phase to 2.5 meters for convenient use in practice [Van Dorsser, 2015]. As a result, it does not matter if a hold is 2.51 meters or 4 meters wide, because either way only one container-wide stowage is possible. If the hold width is 2.51 meters the vessel's hold is "full." In the 4-meter case, only a loading degree of 62.5% can be achieved. *Ceteris paribus*, additional width or breadth of an inland vessel leads to a higher resistance. The result is that the vessel's power demand is higher, resulting in more fuel consumption and therefore higher operational costs. Since the excess width has no use it results in an OPEX that is higher than it could and should be. Appendix C reveals the loading efficiency for non-dedicated vessels carrying standard TEU containers and clearly indicates that there is room for improvement, justifying the next decision.

Reflecting on the existing vessels and their hold dimensions, no specific existing ship was selected. Instead, a scalable design was used as a starting point. The base ship used for further concept design is elaborated on in the subsequent sections. The primary advantage of choosing the scalable design lies in the fair comparison according to which the final concept has to be assessed. Figure 7.1 illustrates the main relationship between ship design and cargo-carrying capacity. The resulting load capabilities are in turn of interest for the cost and revenue calculations.

To ensure the fairest comparison of inland waterway container transport, a series of vessels was designed. The SCCC ensures optimal ship dimensions for each scenario. By result can transport chains consisting of IWT, handling and PPH be optimized and compared to current offered solutions. The SCCC is a previously non-existent concept that was specifically designed in this study for the comparison application.

Sections 7.1, 7.2 and 7.3 contain the three cargo-carrying capacity-defining factors. The primary source for these sections is the estimating algorithms of Hekkenberg [2013], which are relatively recent (ended in 2013) and are therefore assumed to be currently accurate and still representative. No significant changes in the inland market have taken place, and no improved reports have been written since. Van Dorsser [2015] has also used Hekkenberg's [2013] work and has found excellent similarities between the estimating method results and the market averages at that time.

Section 7.4 provides the estimation of building costs for the concept series' hulls. These costs, together with the results from Sections 7.1, 7.2 and 7.3, are used to develop Section 7.5. Additional important factors are briefly discussed in Section 7.6. Intermediate conclusions are drawn in Section 7.7.

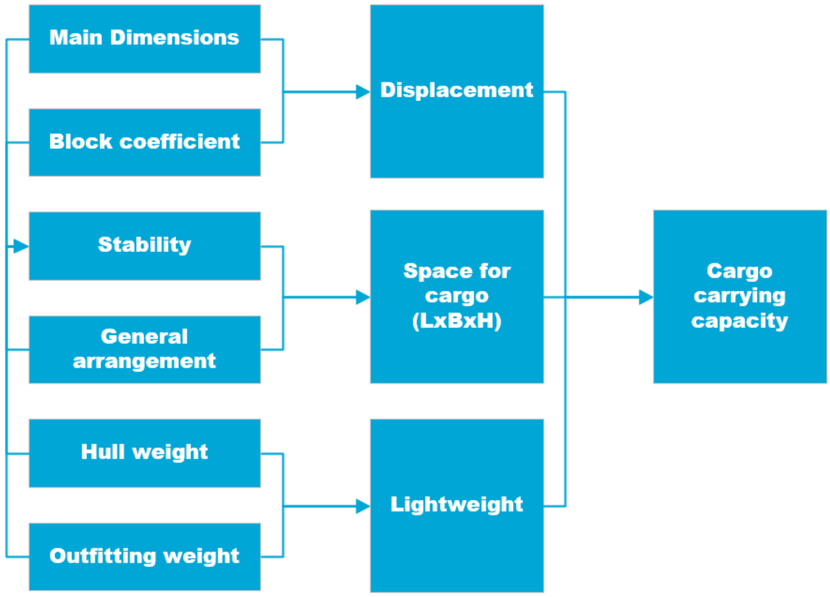


Figure 7.1: Relationship between ship design and cargo carrying capacity [Hekkenberg, 2013]

7.1. Hold Dimensions

Leaving the stern and aft-ship out for now and focusing solely on hold dimensions, the following considerations are made. The capacity of the hold is defined by three parameters, namely the stacking width, height, and length.

The Neokemp ship, a dedicated small container vessel, could initially transport a stack two containers wide and two high. An advanced design known as the Neokemp* makes possible the stacking of an additional layer. For the ships of interest it is then extrapolated that they can carry up to one layer of containers higher than wide under the assumption that, similar to the Neokemp*, active ballast systems can ensure sufficient stability under all conditions.

Breadth (width) limitations for the small inland vessels in CEMT Class IV indicate that the maximum allowed width is 9.5 meters [Rijkswaterstaat, 2017a], which is less than four TEUs wide (10m), forcing the upper limit to three TEUs wide. The cover image of this report pictures such a vessel.

A width of three TEUs automatically means that the maximum stacking height is four TEUs. All vessels can store at least two TEUs high because of their draught and air draught.

Lengthwise, the smallest vessels (Neokemp) have a hold length of approximately 48 meters, meaning that they can carry eight TEUs in length. The largest 105-meter enlarged Rhine-Herne has a hold that can accommodate 13 TEUs.

Table 7.1 has been constructed based on these results. The table is based on a standard TEU container. Stability considerations are not discussed at this point since they are hull-orientated rather than hold-based, but they will be discussed when applicable. In short, the SCCC consists of the following :

- Width: two or three boxes of 2.5 metres.
- Height: A distinction based on stability concerns.
  two Wide: two or three high, as seen on the NeoKemp and Neokemp*
  three wide: two, three or four high, depending on the available air draught.
- : Length: Ranging from 8 to 13 TEU long.

Under the assumptions of Chapter 4, the assumed container composition is 35/60/5 for 20/40/45-foot containers. The concept hold that is 8¬–13 TEUs in length results in FEU lengths of 4–6. To allow for 45-foot containers, the most forward-positioned FEU holds are increased a bit more than 5 feet or 1.5 meters. By elongating the holds 1.7 meters, ease of (un)loading comparable to that produced by having some clearance in width is achieved. In this case, either 25%–15.4% of all holds can accommodate 45-foot containers, which is sufficient for the assumed 5% of cargo. The Neokemp and Neokemp* are also elongated in order to accommodate 45-foot containers.

In some inland vessels, especially the longer types with large, wide holds, a structural frame is placed halfway through the hold. The torsional rigidity requirements can then be matched. In some specific ship types, this *"middengebint"* is left out. It was assumed to be structurally unnecessary for the SCCC and was therefore left out. In case this turns out to be required, it is likely that the bow and stern length can be changed to allow for a small structural hold frame.

The typology for the SCCC is provided in the format *"XYZZ"*, where X indicates the number of containers the ship can accommodate next to each other, Y is the maximum stacking height indicator, and ZZ is the length indicator ranging from eight to 13 TEUs. To clarify this typology, Figure 7.2 illustrates three models and their container loads at full capacity. The 3310 contains a hold capable of transporting three TEUs wide, three TEUs high, and 10 TEUs long. A 3210 can carry one layer less, and the 2310 is a box narrower and allows a maximum width of two containers

Table 7.1: Overview of hold dimensions for a scalable container vessel. Based on standard TEU dimensions as explained in chapter 4.

SCCC	Stacking Order (TEU)				Hold Dimensions (m)				
Type	Wide	High	Rows	Capacity	Width	Height	L_pure	L_add	L_total
2208	2	2	8	32	5.2	5.8	48.8	1.7	50.5
2209	2	2	9	36	5.2	5.8	54.9	1.7	56.6
2210	2	2	10	40	5.2	5.8	61.0	1.7	62.7
2211	2	2	11	44	5.2	5.8	67.1	1.7	68.8
2212	2	2	12	48	5.2	5.8	73.2	1.7	74.9
2213	2	2	13	52	5.2	5.8	79.3	1.7	81.0
3208	3	2	8	48	7.7	5.8	48.8	1.7	50.5
3209	3	2	9	54	7.7	5.8	54.9	1.7	56.6
3210	3	2	10	60	7.7	5.8	61.0	1.7	62.7
3211	3	2	11	66	7.7	5.8	67.1	1.7	68.8
3212	3	2	12	72	7.7	5.8	73.2	1.7	74.9
3213	3	2	13	78	7.7	5.8	79.3	1.7	81.0
2308	2	3	8	48	5.2	8.7	48.8	1.7	50.5
2309	2	3	9	54	5.2	8.7	54.9	1.7	56.6
2310	2	3	10	60	5.2	8.7	61.0	1.7	62.7
2311	2	3	11	66	5.2	8.7	67.1	1.7	68.8
2312	2	3	12	72	5.2	8.7	73.2	1.7	74.9
2313	2	3	13	78	5.2	8.7	79.3	1.7	81.0
3308	3	3	8	72	7.7	8.7	48.8	1.7	50.5
3309	3	3	9	81	7.7	8.7	54.9	1.7	56.6
3310	3	3	10	90	7.7	8.7	61.0	1.7	62.7
3311	3	3	11	99	7.7	8.7	67.1	1.7	68.8
3312	3	3	12	108	7.7	8.7	73.2	1.7	74.9
3313	3	3	13	117	7.7	8.7	79.3	1.7	81.0
3408	3	4	8	96	7.7	11.6	48.8	1.7	50.5
3409	3	4	9	108	7.7	11.6	54.9	1.7	56.6
3410	3	4	10	120	7.7	11.6	61.0	1.7	62.7
3411	3	4	11	132	7.7	11.6	67.1	1.7	68.8
3412	3	4	12	144	7.7	11.6	73.2	1.7	74.9
3413	3	4	13	156	7.7	11.6	79.3	1.7	81.0

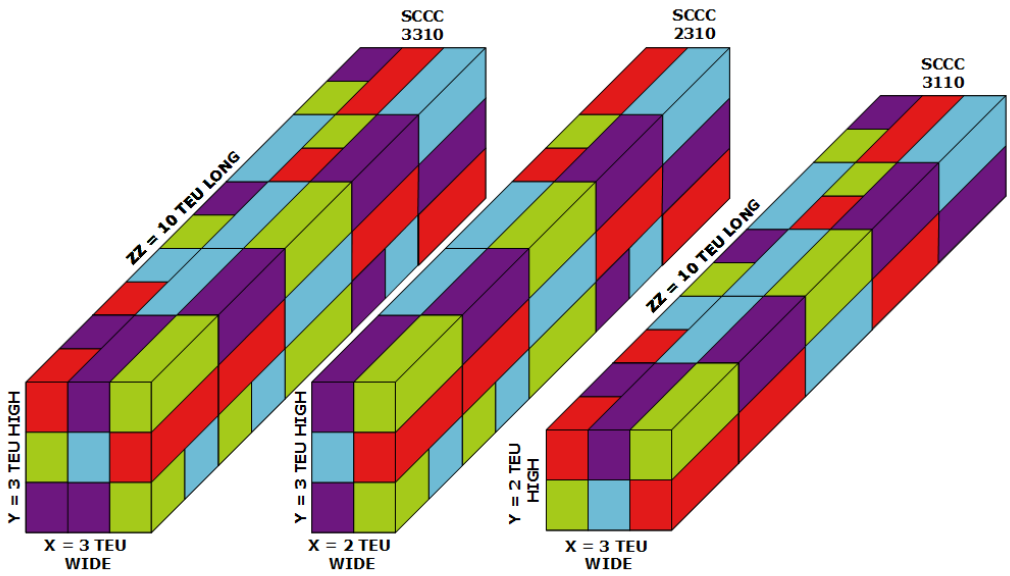


Figure 7.2: Capacity impression for three different SCCC types.

7.2. Hull Dimensions

Section 7.1 contained the construction of a three-dimensional hold series that in total added up to 30 different hold configurations. These holds are each only part of a complete ship design. A hull is first fitted around the hold; therefore, Subsections 7.2.1, 7.2.2 and 7.2.3 are necessary. In turn, that information is used to reveal the resulting hull dimensions for the SCCCs in Subsection 7.2.4.

7.2.1. Breadth

For the width of the hold, roughly 2.5 meters is required per TEU. In addition to the hold two gangways are always present, adding up to the vessel's total width or breadth. The gangway width was estimated by looking at two reference vessels, the Neokemp and a CEMT Va dedicated container barge. For the Neokemp, which has a width of approximately 7 meters, the gangways are 1 meter each. The Neokemp can carry two TEUs wide and high, making the hold 5 meters wide. The Neokemp* is 20 centimeters wider, increasing the stability of the third row of containers. It is therefore assumed that for the concept vessels that carry one layer more in height than in width, 20 centimeters has to be added to the breadth. Due to the limited ship width and the stability requirements, the sides of the Neokemp are most likely larger than structurally required.

The larger Va vessel is 11.45 meters wide and carries up to 4 TEUs wide, having a hold width of 10 meters. Its gangways are thus roughly 0.75 meters each. [1] The effect of one container more or less is far less significant for this type of vessel, which can carry up to 200 TEUs. The gangways are therefore narrower than those of the Neokemp. This leads to the following assumptions:

- 2 wide x 2 high → 0.9 meters
- 2 wide x 3 high → 1.0 meters
- 3 wide x 2 high & 3 wide x 3 high → 0.8 meters
- 3 wide x 4 high → 0.9 meters

Article 11.04 from the European Commission[2] states that the gangway should have a width of at least 60 cm at undisturbed parts. For the points at which boulders are located at the path , 40 cm suffices. The aforementioned gangways are therefore assumed reasonable and in line with the rules. Additionally, Articles 22.02 and 22.03 state the minimum requirements concerning the stability of the inland vessel. To verify whether or not the aforementioned assumptions are realistic and sufficient, stability calculations of a simplified SCCC hull have been made. Appendix N contains these calculations and additional explanations. The results indicate that the additional width is required for adequate stability, therefore justifying the previous statements.

[1] For the gangway width, the hatch coming is incorporated. In practise the gangway will be thus slightly smaller than the dimensions mentioned here.

[2] European Commission; Directive of the European Parliament and of the Council [2006]

7.2.2. Length

The vessel's total length is estimated in a similar manner. The original Neokemp has a total length of 63 meters. The hold is 49 meters long, making the bow and aft-ship a combined 14 meters. A CEMT Va holds 13 TEU bays, coming in at 13 times 6.1 meters, or 79.3 meters. The vessel's total length is 110 meters, making the bow and aft-ship approximately 30 meters.

This difference is mainly caused by the difference in the uses of these vessels. Large inland vessels are not sailed by a captain alone; they also have some additional men on board for engine room maintenance, etc. This requires additional housing in the aft-ship. Additionally, equipment is increasing in size simply because the ships are getting bigger. A second main engine is often installed, and bow thrusters have to be larger. Finally, as the width of vessels increases, the bow and stern are made longer to reduce the resistance. The Froude number of a short vessel is relatively higher than that of a longer ship at the same speed. As a result, the resistance contributions of the different components differ, requiring other hull shapes.

For the dedicated container concept ships, this translates to the following bow and aft-ship lengths: the two-TEU width is in keeping with the Neokemp layout, heaving bow and aft at 14 meters. The three TEU-wide ships have different lengths. They are, however, wider than CEMT III and somewhat smaller than CEMT IV. It is expected, however, that for manned sailing, the same rules as regular CEMT IV vessels would apply. The same aft-ship dimensions are therefore used, and the bow length is scaled with the changed width.

A IV Rhine-Herne ship can carry up to 10 TEUs in length, having a hold of at least 61 meters. With a max IVa length of 86 meters, the bow and aft-ship thus come to a total of 25 meters. For the slimmer concept, the length of bow and aft-ship is set at 20 meters for ships up to 80 meters long, and 24 meters for ships up to 105 meters long.

- $L < 70 \rightarrow$ Bow+Stern = 14 meters
- $70 \leq L < 80 \rightarrow$ Bow+Stern = 20 meters
- $L \geq 80 \rightarrow$ Bow+Stern = 24 meters

Appendix E shows the minimum required crew composition according to the RPN rules of the CCNR. The Regulations for Rhine Navigating Personnel state that different minimal compositions of personnel are required under different sailing conditions. This means that not only are more personnel costs incurred, but in most cases additional crew space also has to be available. Given the premeditation of the concepts' sailing profile, most likely to be A2 (S2), 18 hours for five days, thus requiring the middle type of accommodation.

Reflecting on the introduction of Chapter 3, inland shipping also faces personnel shortages, mainly caused by the lack of young captains/owners of that want a life aboard an inland vessel. As a result, more and more day sailing that allows the captains to return home at night is being pursued. The European Novel IWT and Maritime Transport Concepts (NOVIMAR) project, for example, has also performed research related to this challenge.

7.2.3. Draught and Air Draught

The third dimension of the scalable container concepts is that of the draughts, both below and above water. Whereas length and beam are carefully chosen dimensions, draught could be considered a resulting dimension. Given a certain capacity, the draught is a resulting measure following Archimedes' Law. [3] Since the container is low-density cargo, inland container vessels with a draught of more than 3.5 meters do not exist [Hekkenberg, 2013].

For a vessel like the Neokemp, the maximum draught is 2.8 meters at 800+ tonnes of payload. With its 32-TEU capacity multiplied by a maximum of 30 tonnes per TEU, the Neokemp could in theory achieve a payload above 800 tonnes. In practice, given the average 15-tonne weight of a TEU including its tare weight, [4] the Neokemp sails at a draught between 1.25 and 2 meters. The advanced version, the Neokemp*, can carry an additional layer. For stability reasons this cannot be a layer of full containers, thus limiting the draught to approximately 2.3 meters. Similar limitations are likely to be applicable to the scalable series. The design draught is, however, significantly less than that of normal dry bulk vessels, since the concept is designed to be a dedicated container carrier. The effect of less draught is explained in Section 7.5.2.

[3] Archimedes' Law states that the buoyancy force is equal and opposite to the weight of the displaced volume.
[4] see chapter 4 subsection 4.1.2 for more information about container weight.

As a result, the concepts have operational draughts that are half a meter less than their scantling draughts. Given the rules and the desire to be able to change the draught and air draught, the scantling draughts are relatively deep. Whereas scantling draughts vary between 3 and 3.5 meters, the operational, loaded draughts vary between 2.5 and 3 meters. Fully empty draughts are the result of the lightweight and the minimum amount of ballast required to fulfill stability requirements. Since no advanced resistance and propulsion are incorporated into the design, the exact empty values are unknown. It is assumed, however, that based on general rules, the empty draughts are assumed to be 1.5 meters.

The result of a limited draught is the remaining stack height above water, known as the air draught. Infrastructural limitations such as fixed bridges have a significant impact on the navigating air draught. The submerged stack portion is the hull draught minus the double bottom thickness. The air draught is the remaining portion of the container stacks. In a supercritical design, the height of the double bottom may be reduced to the absolute minimum to increase the submerged part. On average, however, a value of 0.5 meters is assumed for the double bottom.

The result of air draught limitations can be that not all configurations can be sailed. It can be the case, for example, that all layers can contain HCs, or that only some of these layers can contain HC containers. That is all dependent on the air draught limitations. Resulting air draughts are given two values: one contains the upper limit when loaded with HC only, and the other is based on regular containers only. Both are based on the assumed operational draughts.

7.2.4. Resulting Hull Dimensions

Table 7.2: Overview of main dimensions of scalable concept. RC = Regular Container and HC = High Cube Container.

SCCC	Hull Dimensions (m)						
Type	L	B	T_d	T_s	T_empty	T_air_HC	T_air_RC
2208	64.5	7.0	3.0	2.5	1.5	3.8	3.2
2209	76.6	7.0	3.0	2.5	1.5	3.8	3.2
2210	86.7	7.0	3.0	2.5	1.5	3.8	3.2
2211	92.8	7.0	3.0	2.5	1.5	3.8	3.2
2212	98.9	7.0	3.0	2.5	1.5	3.8	3.2
2213	105.0	7.0	3.0	2.5	1.5	3.8	3.2
3208	64.5	9.3	3.0	2.5	1.5	3.8	3.2
3209	76.6	9.3	3.0	2.5	1.5	3.8	3.2
3210	86.7	9.3	3.0	2.5	1.5	3.8	3.2
3211	92.8	9.3	3.0	2.5	1.5	3.8	3.2
3212	98.9	9.3	3.0	2.5	1.5	3.8	3.2
3213	105.0	9.3	3.0	2.5	1.5	3.8	3.2
2308	64.5	7.2	3.4	2.9	1.5	6.3	5.4
2309	76.6	7.2	3.4	2.9	1.5	6.3	5.4
2310	86.7	7.2	3.4	2.9	1.5	6.3	5.4
2311	92.8	7.2	3.4	2.9	1.5	6.3	5.4
2312	98.9	7.2	3.4	2.9	1.5	6.3	5.4
2313	105.0	7.2	3.4	2.9	1.5	6.3	5.4
3308	64.5	9.3	3.2	2.7	1.5	6.5	5.6
3309	76.6	9.3	3.2	2.7	1.5	6.5	5.6
3310	86.7	9.3	3.2	2.7	1.5	6.5	5.6
3311	92.8	9.3	3.2	2.7	1.5	6.5	5.6
3312	98.9	9.3	3.2	2.7	1.5	6.5	5.6
3313	105.0	9.3	3.2	2.7	1.5	6.5	5.6
3408	64.5	9.5	3.5	3.0	1.5	9.1	7.9
3409	76.6	9.5	3.5	3.0	1.5	9.1	7.9
3410	86.7	9.5	3.5	3.0	1.5	9.1	7.9
3411	92.8	9.5	3.5	3.0	1.5	9.1	7.9
3412	98.9	9.5	3.5	3.0	1.5	9.1	7.9
3413	105.0	9.5	3.5	3.0	1.5	9.1	7.9

7.3. Lightweight & Deadweight

The hulls listed in Table 7.2 are only dimensioned in terms of size. No weights or corresponding costs have been assigned. To begin determining the weights, this section explores the determination of the lightweight. After this, Subsection 7.3.2 explains the determination of the corresponding deadweights.

7.3.1. Lightweight

In order to forecast the vessel-associated cost algorithms for building costs, Hekkenberg's concepts of lightweight and deadweight are used. [5] Beginning with the lightweight, or empty outfitted hull, four equations are provided, namely Equations 7.1, 7.2, 7.3 and 7.4. In Appendix K, Tables O.1, O.2 and O.3 list the coefficient values for these approximation formulas.

$$W_{steel} = c_1 + c_2 \cdot LB + c_3 \cdot L^2 T + c_4 \cdot LBT + c_5 \cdot L^{3.5} B + c_6 \cdot \frac{L^{1.3} T^{0.7}}{B} + c_7 \cdot \frac{1}{B^2 T^{1.5}} \tag{7.1}$$

$$W_{acc} = 0.173 \cdot 2.5 \cdot \text{Maximum of:}[L/4 \cdot (B-2), 100] \tag{7.2}$$

$$W_{piping} = c_1 + c_2 \cdot L + c_3 \cdot B + c_4 \cdot T + c_5 \cdot LBT \tag{7.3}$$

$$W_{m,e,o} = c_1 + c_2 \cdot T + c_3 \cdot LB + c_4 \cdot LBT + c_5 \cdot \frac{1}{L^3} \tag{7.4}$$

7.3.2. Deadweight

The third part of Hekkenberg [2013] estimations is the cargo-carrying capacity of deadweight. While Hekkenberg has referred to the aforementioned algorithms as advanced, Equation 7.5 has been deemed a simple approaching method. No advanced equation is required. Table O.6 in Appendix O provides the coefficients. Table O.7 provides the linearly interpolated values used for the intermediate values. Linear interpolation has provided an accurate estimation for all three constants. Data analysis revealed an R^2 of at least 0.986.

$$W_{cargo} = c_1 \cdot (LBT)^2 + c_2 \cdot LBT + c_3 \tag{7.5}$$

In parallel with the approaching method, it is also known that deadweight plus lightweight must be equal to the displaced water weight; therefore, the underwater volume ∇ is first calculated. The block coefficient is estimated to be 0.75 for the *'XY08'*-models. The longer models have corrected coefficients based on additional midship length. This additional section has a midship coefficient of 0.95, thereby increasing the overall block coefficient of the longer SCCC versions. The displaced volume then becomes $c_b \cdot L \cdot B \cdot T \cdot = \nabla$. Inland water is assumed to have a density of 1 ton/m^3, making the displaced volume equal to the displaced weight.

Subtracting the estimated lightweight from this displaced weight then provides an estimated deadweight. This “Nabla-LW” can then be compared to the algorithm results. The results indicate a small overestimation of the deadweight when subtracting the lightweight from the displaced weight. The overestimation lies in the range of -5% for the smaller vessels to 12% for the large types. Given that the lightweight is an estimate and that the block coefficient is estimated and not directly based on a calculated hull, the difference is acceptable. Given the purpose of this figure, which is forecasting the carrying capacity, the numbers are reasonable. As a result, the values based on nabla minus the lightweight are used for further calculations.

7.4. Building Cost

Similar to the approaching method for lightweight, building costs can be estimated with great certainty. Equations 7.6 and 7.7 provide the approaching formulas. The coefficient values are provided in Appendix O, Tables O.4 and O.5. The yard costs form the bare hull cost including material, manpower, and facility costs. Non-yard costs of the vessel consist of the installed equipment, machinery, and outfitting. Whereas the yard costs are container vessel-specific, in this case assumed transversely framed, the non-yard costs are deemed dry bulk general.

[5] The algorithms are derived with a Ordinary Least Squares (OLS) regression. Resulting approximation formula's showed excellent fits with a significant database. All approximations have R^2 values above 0.95, meaning they cover the vast majority of the variance in the original data. When the input lies within the original data set and does not cover a completely different vessel type the outcome is representative.

Hekkenberg [2013] has stated that the only difference between a container and a dry bulk vessel lies in the bare hull costs, therefore justifying this assumption. The resulting estimated vessel cost can be found in Table 7.3. Comparing the cost values to known hull prices gives one reason to believe that the prices are reasonable and accurate [Buck Consultants Rotterdam, 2008].

The original source cost estimations were found for the base year 2011. Translating these values to 2018 values is a delicate task given several influencing factors. Examples of these factors are, for instance, changing steel prices; changing currency exchange rates; production locations that might have changed, meaning different labor costs are incurred; and the changing market conditions leading to different margins at yard. How these factors have influenced building cost is deemed outside of the scope of this thesis for the time being. The values in the third column of Table 7.3 are therefore assumed to be accurate for 2018.

$$Cost_{yard} = c_1 + c_2 \cdot LB + c_3 \cdot L^2 T + c_4 \cdot LBT + c_5 \cdot L^{3.5} B + c_6 \cdot \frac{L^{1.3} T^{0.7}}{B} \tag{7.6}$$

$$Cost_{misc} = c_1 + c_2 \cdot \frac{L^{1.5}}{B} + c_3 \cdot LBT + c_4 \cdot LB + c_5 \cdot \frac{1}{LT} \tag{7.7}$$

Table 7.3: Estimated values for lightweight, dead weight and hull cost (base year = 2018). (Based on Hekkenberg [2013])

SCCC Type	Lightweight Total	Cost Hull & Outfitting Total (Excl. Handling eq.)	Cargo Capacity (t) Hekkenberg	Cargo Capacity (t) Nabla-LW	Displacement cb	Displacement nabla
2208	289	€ 1,590,000.00	739	727	0.750	1016
2209	332	€ 1,840,000.00	896	926	0.782	1258
2210	374	€ 2,060,000.00	1026	1085	0.801	1459
2211	401	€ 2,200,000.00	1104	1180	0.811	1581
2212	430	€ 2,340,000.00	1182	1273	0.820	1703
2213	461	€ 2,490,000.00	1260	1363	0.827	1824
3208	324	€ 1,800,000.00	1013	1026	0.750	1350
3209	380	€ 2,100,000.00	1219	1291	0.782	1671
3210	430	€ 2,360,000.00	1390	1509	0.801	1939
3211	462	€ 2,520,000.00	1492	1638	0.811	2100
3212	495	€ 2,690,000.00	1594	1767	0.820	2262
3213	530	€ 2,870,000.00	1696	1894	0.827	2424
2308	307	€ 1,660,000.00	921	878	0.750	1185
2309	354	€ 1,910,000.00	1114	1112	0.782	1466
2310	400	€ 2,140,000.00	1274	1301	0.801	1701
2311	430	€ 2,290,000.00	1371	1413	0.811	1843
2312	460	€ 2,430,000.00	1468	1525	0.820	1985
2313	493	€ 2,590,000.00	1564	1634	0.827	2127
3308	333	€ 1,830,000.00	1115	1107	0.750	1440
3309	391	€ 2,130,000.00	1341	1391	0.782	1782
3310	442	€ 2,390,000.00	1529	1626	0.801	2068
3311	474	€ 2,550,000.00	1642	1766	0.811	2240
3312	508	€ 2,730,000.00	1754	1905	0.820	2413
3313	545	€ 2,910,000.00	1866	2040	0.827	2585
3408	350	€ 1,890,000.00	1304	1259	0.750	1609
3409	412	€ 2,190,000.00	1568	1579	0.782	1991
3410	465	€ 2,460,000.00	1788	1845	0.801	2310
3411	500	€ 2,630,000.00	1920	2003	0.811	2503
3412	535	€ 2,810,000.00	2051	2161	0.820	2696
3413	573	€ 2,990,000.00	2183	2315	0.827	2888

Up to this point, the hold and hull dimensions have been determined. Additionally, the lightweight or ships' own weight has been estimated, and the cargo capacity or deadweight has been estimated via two different methods. Finally, the bare hull building costs have been estimated, the result being that at this point the dimensions, weights, and vessel costs of the thirty SCCCs are known. With these numbers, the economic profile can be determined, which is therefore the subject of the next section.

7.5. Operational Cost

Similar to the relationship between ship design and cargo carrying capacity, Hekkenberg [2013] has also discovered the main relationship between ship design and vessel costs. Figure 7.3 illustrates that the costs are dependent on the capital cost, the required Return on Investment (ROI) and the running costs. The capital costs are the result of building cost. These building costs define to a large extent the required loan sum and the cost of that loan. Running costs are the sum of the use of consumables, R&M and the crew or labour cost. Most left boxes in Figure 7.3 show the influencing factors that define these cost. These four basic inputs have been discussed in the previous sections.

An overview resulting from this relationship model is provided in Table 7.4. This stepwise process from earnings to net result has been discussed in Subsection 3.1.2. Earnings are the subject of later chapters when the concepts' market adoption is studied. This section focuses solely on costs. Table 7.4 has been modified somewhat to better fit the SCCC's operational cost structure.

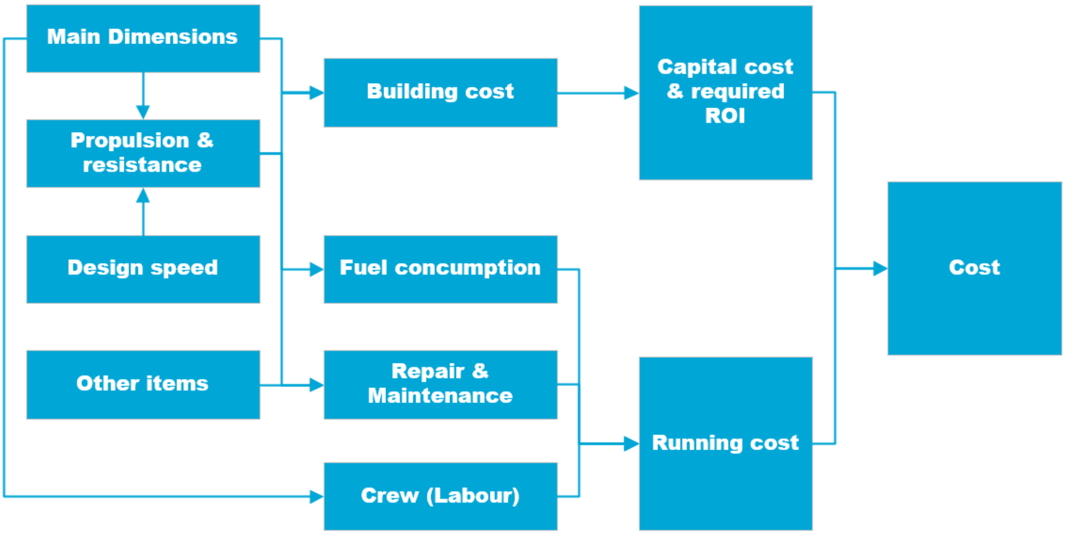


Figure 7.3: Relationship between ship design and cost according to Hekkenberg [2013]

Table 7.4: Overview of all costs between earnings and the net result. ([Hekkenberg, 2013], modified version)

Earnings	TEU-rate * # of TEU transported	1
Operational Expenditure	Labour	2
	Fuel	3
	Repair & Maintenance	4
	Insurance	5
	Overhead	6
GC approach	Internalized external cost	7
EBITDA		8 = 2 + .. + 7
Devaluation	Depreciation	9
	Amortization	10
EBIT		11 = 8 - 9 - 10
Capital cost	Interest	12
EBT		13 = 11 - 12
Taxation	Tax-rate	14
Net result		15 = 13 - 14
Loan repayment	Principle payment	16
Free Cash Flow		17 = 15 + 9 + 10 - 16

7.5.1. Labour Cost (2)

An introduction of IWT labor costs has already been provided in Chapter 3 (Subsection3.1.2). Wages can differ significantly depending on the nationality of the vessel and/or the crew. Labor costs are also influenced by the flag state tax system. As a result, it has recently been discovered that between different countries the wages can differ by as much as 30–50% per annum [Rebelgroup et al., 2015]. Additionally, own staff or hired personnel make a large difference. Wages are what staff earn, but these are not the ship owner's full costs of hiring staff, which also include vacation bonuses, insurance, and pension charges. The result is a multiplication factor of 1.75 that is applied to the gross wages to obtain an estimate for the labor costs, as proposed in Subsection 3.1.2 Implementing the 1.75 gross wage to labor costs created a good comparison with the market data from Van der Meulen and Van der Geest [2016].

Additionally, two full crews are required for Sailing Scheme B. To include the effect of different sailing schemes, the A2 costs use a 16% overtime (OT) premium, which can be found in table E.3. The sailors operating on Scheme B have been assumed to be receiving 24% OT and 19% Saturday and Sunday premium (SSP). For own crews, these monthly wages multiplied by the labor cost factor add up to the monthly labor cost. Further calculations use the annual labor cost per crew and divide that by the crew's maximum operational days. The result is an estimate of the daily labor cost. A crew operating on a part-time basis is unlikely to be own crew, therefore requiring hired staff. This hired staff is more expensive, increasing the ship owner's costs. As a result, external staff is expected to cost an average of 10% more than own staff. The available range adopted is 0% to 20%.

Company specifics such as the effective contracted hours are excluded in order to limit the uncertainty and complexity of calculations. A day-sailing vessel owner could, for instance, decide to hire staff for 12 instead of 14 hours, which reduces the costs. For ease of comparison, labor costs are only calculated for full days. A sailing round trip that takes 3.7 days will therefore incur labor costs equivalent to four days. The resulting annual wages are listed in Table 7.5. According to the labor cost trends found, the annual labor cost increase is 3% in the long run [Panteia, 2004]. These increases are important to incorporate since, for example, the labor cost of the 25th year of a 25-year investment period is 2.09 times higher than the labor costs of the first year. Appendix E lists the minimum required crew [CCNR, 2016].

Table 7.5: Annual labour cost depending on the sailing schema and vessel size (base year = 2018) CCNR [2016]

Length (m)		Operating scheme					
		A1, 14h / 5 days		A2, 18h / 5 days		B, 24h / 7 days	
		S1	S2	S1	S2	S1	S2
0.00	70.00	€ 82,740	€ -	€ 104,160	€ -	€ 459,480	€ 446,460
70.01	86.00	€ 84,000	€ 116,550	€ 144,480	€ -	€ 477,120	€ 464,100
86.01	135.00	€ 123,480	€ 118,860	€ 190,470	€ 185,220	€ 594,300	€ 581,280

The different sailing schemes can only be put into operation when the vessel can accommodate the required crew. In Subsection 7.2.2, three different bow and stern lengths were assumed. The three different operating levels can be provided for these lengths. The smallest vessels ≤ 70 meters can only accommodate A1, while 70 m ≤ L ≤ 86 m allows both A1 and A2. The SCCCs larger than 80 meters are assumed to be able to accommodate A1, A2, and B sailing profiles.

In the current market, most inland container vessels operate according to Profile B, followed by Profile A2 [Van Kester, 2014b]. Profile A1 is not currently operated by dedicated container transport, the primary reason for which is most likely to be the need for speed. In many cases, operating the more intense profiles means a full day gained compared to Profile A1. Additionally, a higher frequency can be achieved with fewer ships, and the existing dedicated inland container vessels are large and operating on tight time schedules. To reduce the operating cost per TEU, maximum sailing time is pursued. Smaller vessels are primarily operated according to Profile A1, while the largest vessels are primarily operated according to Profile B [Van Kester, 2014b]. Overall, it is assumed that the *"XY08"* is operated according to A1 and *"XY09"* is operated at A2, while *"XY10"* through *"XY13"* are operated according to either A2 or B.

Based on the assumed 50 annual operational weeks minus some days of leave for all profiles, 46 working weeks are assumed. [6] At five days for A1 and A2 and seven for B, the annual working days are 230/230/322 for A1/A2/B, respectively.

[6] This would mean 30 days per year of paid leave. Given the need for personnel this seems reasonable to attract personnel

Table 7.6: Daily labour cost depending on the sailing schema and vessel size (base year = 2018). Costs are rounded up to integer values and without an additional hire premium.

SCCC Type	Operating scheme			
	A1	A2		B
	S1	S1	S2	S2
XY08	€ 360	-	-	-
XY09	-	€ 629	-	-
XY10	-	-	€ 629	€ 1864
XY11 - XY13	-	-	€ 806	€ 1864

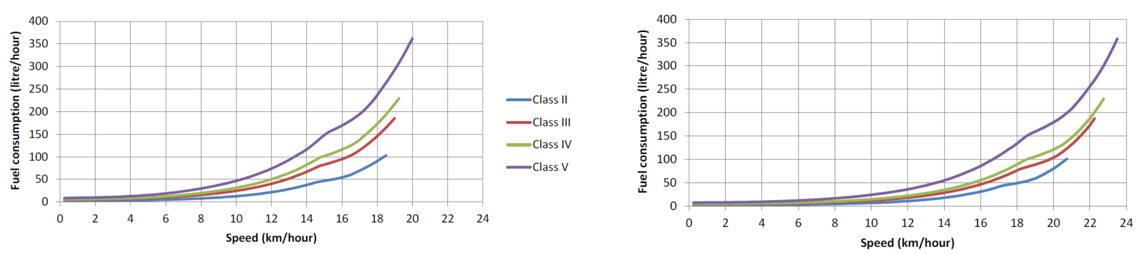
7.5.2. Fuel Cost (3)

The main variable used to determine the operational expenditure is fuel usage and thereby fuel cost. Inland vessels are operated on waterways with and without currents, have different loading conditions defining their draught, and can be used at different speeds. While a truck or train has to adhere to a certain speed, inland shipping is roughly free to determine its sailing speed. Especially when sailing the larger rivers, currents can be quite significant, especially in comparison to the vessel's speed. The vessel's speed can be expressed in its speed through water and the speed over the ground. For example, Van Dorsser [2015] has assumed a current of 4 km/hour. At a current-free sailing speed of 16 km/hour, this current could increase/decrease the effective speed by 25%.

On the upstream part of the trip this current is of course working against the vessel, lowering the effective speed over the ground. On the downstream journey, however, the current is beneficial to the speed over the ground. The speed through water can become critical, as Hengst [1995] has mentioned. When the ship's speed rises above 70% of the critical speed, the resistance increases significantly ($v_{critical} = \sqrt{g * h}$ with v in m/s, g = 9.81 m/s^2 and h = waterway depth in metres).

Different currents are present throughout the Blue Corridor, differing from location to location and dependent on the river slope and the weather earlier in the delta. Near Koblenz, currents allegedly range between 1 km/h in periods of drought to over 5 km/h after long periods of rain. Specific cases can demand additional installed power for both safety and economic operation. The tool (explained in Section 7.7) will allow for different specific cases. It is also known, however, that many inland vessels are overpowered due to the fact that their design speed (greatly) exceeds their actual operating speed. To prevent this costly mistake, an average current of 3km/h is selected. Lower currents are expected on the smaller waterways. In case of an even division between large and small waterways, the assumption is based on 4 km/h resp. 2 km/h of current. Averaging provides a current of 3 km/h.

Figure 7.4a illustrates the to-be-expected scenario under design conditions. The hump in the line is caused by the hull operating at the design speed, which locally reduces the resistance. Loading standard barges with 45-foot containers leads to an insufficient utilization of the cargo holds [Van Dorsser, 2015]. As previously mentioned, there can only be an integer amount of containers stored in the hold, leading to excess hold space. Additionally, containers are relatively low, dense cargo. Combining the excess unused space and the low, dense cargo, the effective payload for standard barges carrying containers is significantly lower than the design conditions. Figure 7.4b indicates that, for example, a Class V vessel traveling 14 km/hour is only consuming 55 liters per hour compared to 120 liters per hour for the design conditions. This means that the fuel consumption for such conditions is roughly half that of the expected design conditions. This underscores the advantage of the scalable container carrier concept.



(a) Fuel consumption of standard vessels at design draft. [Van Dorsser, 2015]

(b) Fuel consumption of standard vessels loaded with full 45 foot containers. [Van Dorsser, 2015]

Figure 7.4: Difference in fuel consumption under different conditions

Estimating these costs was one of the research goals of Hekkenberg's [2013] doctoral thesis. As Hekkenberg has stated, *"While a ship's design has a major impact on the cost of transport, much is still unknown about the relationship between the design of an inland ship and the cost of transport."*.

The fuel usage is primarily dependent on the following parameters:

- Specific Fuel consumption (SFC) of the engine
- Installed power
- Required power
    - Design draught and sailing draught
    - Waterways depth and keel clearance
    - Navigation speed and design speed
    - Currents

For relatively small engines (≤ 1,200 kW) specific fuel consumption (SFC) is around 220 g/kWh [Klein Woud and Stapersma, 2008]. Gasoil has a density of around 840 kg/m^3, which leads to an approximated fuel flow of 0.262 l/kWh. This SFC only holds true at a maximum continuous rating (MCR) of more than 60%. At smaller part loads (for example, 25% MCR), the SFC increases to ≈ 10% increased values. Equation 7.8 provides the formula based on Klein Woud and Stapersma [2008].

$$\text{SFC} = \text{Maximum of :}[220 \text{ or } 0.008 \cdot MCR\%^2 - 1.39 \cdot MCR\% + 280] \tag{7.8}$$

The required power of the SCCC has been determined with the admiralty constant "C". After fitting current inland vessels, a constant value of 185 has been selected. The selected design speed is 18 km/h, or 9.72 knots. With the assumed currents averaging 3 km/h, the SCCC can attain an average speed of 15 km/h. This suffices the minimum navigation speeds of 13 km/h stated by the rules [European Commission; Directive of the European Parliament and of the Council, 2006].

In inland navigation, speeds and distance are more often displayed in kilometers and hours than in knots and sea miles, justifying the choice of an integer design speed in kilometers per hour. The required power can be calculated using the earlier calculated displacements (in tons), the design speed (kn), and the ship type-dependent constant ($T^{2/3}kn^3/kW$). The feasibility analysis also contains an analysis regarding the effect of reducing the maximum attainable speed. Although Equation 7.5.2 only incorporates friction resistance, its results are deemed sufficient for this purpose since it is used for the extrapolation of existing inland vessel propulsive power to the SCCC's required power.

Since engines are best used just below maximum power, the required power is assumed to be 85% of the installed power. This operating point leads to substantially lower R&M while the power output is still sufficient. Whereas the SCCC is assumed to be equipped with a modern hull, the installed power is not much lower than that of current vessels. For container vessels, especially when navigating small waterways, the margin for error is very small. As a result, it is assumed that sufficient installed power is required for certainty and reliability of service. Compared to standard dry bulk vessels, container vessels have more height, leading to larger wind-induced forces. Additionally, given the shallower draught the ship will in practice be more prone to these effects , requiring additional power. Whereas the advanced hull may be less power consuming, the installed power will thus be in line with existing vessels.

$$P_{req} = \frac{\Delta^{2/3} \cdot V^3}{C} \tag{7.9}$$

The effect of draught is assumed to be linear. In practice, the hull will become more streamlined at lower draughts, but at the same time the propeller will become less efficient. These effects are assumed to cancel out within the reasonable draught spectrum.

The waterway depth influences the critical speed. When the ship sails at above 70% of the critical speed, additional power is required. This effect can result in two cases: either more power is required, or the speed is naturally decreased. Under the assumption of constant speed, the demand for power will increase. Since this effect is highly dependent on waterway specifics and hull dimensions, no generic formula has been found. Equation 7.10 is therefore proposed to incorporate this effect.

Residual draught under the keel is only of importance below 0.5 meters [Hengst, 1995]. Given the variable loading of containers, this is always (or most of the time) assumed to be the available keel play.

$$PowerFactor_{criticalspeed} = \text{Maximum of 1 or} \sqrt{\frac{c_{sailing}}{70\% of\, v_{crit}}} \tag{7.10}$$

Navigation speed versus the design speed of the vessel is the most significant influencing factor together with the loading conditions. Bare hull resistance increases to the second power at increasing speeds; therefore, the required power increases to the third power. The result is that for the design conditions, significant power that is not used at low operating speeds needs to be installed. For example, consider a vessel sailing at 18 km/hour that has 1,000 kW of propulsive power. Reducing the speed to 12 km/hour lowers this power to 296 kW, which is a 70.4% reduction.

The concepts use a relatively standard diesel engine power train. Current interest in other fuels is still relatively new and not widely adopted. For comparison purposes, the conventional engine configuration is adhered to. The possible effects of other power train options are discussed later on in the analysis.

Additionally, given the different loading conditions and the combination of current and sailing speed, the power used by an inland container vessel varies. At part loads less than approximately 60% of installed power the specific fuel consumption starts to increase [Klein Woud and Stapersma, 2008]. To prevent engines from operating far below this level, a dual engine configuration is proposed that will shut down one engine if the required power is less than 45% of the installed power. The result will then be that the other engine will no longer operate at, for instance, 40% MCR, but will double its power production to a more efficient operating point of 80% MCR.

The effect of a number of reefer containers and their power consumption is impossible to determine accurately. To prevent an incorrectly estimated power markup, it is assumed that the effect is negligible and falls within the existing assumed power demand.

The default fuel price used in the model is the most important. The running average of 2018 is around €650/m^3 [Contargo, retrieved table for June 2018 on 03/05/2018], which was selected as the value for this thesis' calculations. The subject of the feasibility study will be to investigate the effect of the fuel price on the competitiveness and viability of the concept.

7.5.3. Repair & Maintenance (4)

Based on the regression made in Section 3.1.2, two equations for the estimation of R&M costs have been found. Equations 7.11 and 7.12 calculate these estimations. The resulting cost estimators are for the ship only, meaning that no specific handling equipment has yet been incorporated. These specific costs are the subject of the next chapter when the terminal integration is conceptualized. It is important to note the difference between the fixed R&M, which is based on the design displacement, and the variable R&M, which is based on the operational displacement.

Fixed R&M includes elements such as paint, interior, electronics, etc. No matter the loading condition, these parts wear at the same rate. The variable R&M includes the engines, holds, and hull plating. These parts are stressed more by higher usage, therefore increasing the R&M cost.

$$R\&M_{fixed} = €6.2 * \textit{Design displaced Volume} + €1200 \tag{7.11}$$

$$R\&M_{variable} = €2.1 * \textit{Operational Displaced Volume} + €850 \tag{7.12}$$

7.5.4. Insurance and Overhead (5 & 6)

Insurance costs can be calculated reasonably by taking 1.5% of the vessel's current value [Buck Consultants Rotterdam, 2008]. It is assumed that the concept's hull and outfitting insurance is equal to that of a standard dry bulk inland vessel. The author expects the optional equipment to be insured at the same rate.

Overhead, consisting of o.a. affreightment, accountancy, office expenses, and representation, is estimated to be 2.5% of annual earnings at a minimum of €25,000 [Van Dorsser, 2015]. It is too cumbersome and uncertain to estimate these costs exactly. Given their limited impact the estimation is not supercritical, but incorporating these costs creates a more realistic comparison.

The additional ARA charge (€2.02 per TEU) has also been adopted. This charge was discussed in Subsection 3.1.2.

7.5.5. Internalized External Costs (7)

Based on the work done in Subsection 3.1.3 , the ECs of IWT that could be internalized are limited to the marginal air pollution. The values listed in Table 7.7 were calculated in Chapter 3 and are implemented in the model.

Table 7.7: Updated external costs for IWT and base year 2018.

External Cost	3. Air Pollution	5. Climate Change	6. Well-to-tank
Unit measure	€/1000tkm	€ct/l MDO	€ct/vkm
Value	1.3	34.6	1.1
Potentially Internalised	Yes	No	No

For air pollution, the distance and weight are of importance. The weight is (under the assumption that the water density is 1 t/m^3) equal to the displacement of the vessel under its specific loading conditions. An accurate assumption can be made using a presumed load and the respective container weights.

Similarly, climate change-associated costs can be calculated given the fuel consumption calculations used to determine fuel cost. Finally, the sailing distance is also used to calculate the well-the-tank external effect.

7.5.6. Capital Costs and Expenses (all other)

Following the analysis conducted in Chapter 3 (subsection 3.1.2), the loan sum has an assumed WACC of 6%. The effects of a higher risk premium of 8% will also be studied. Interest payments are the result of the remaining loan and the applying interest rate. It is assumed that the SCCC and handling equipment to be designed and selected in the next chapter are all under the same financial conditions.

With the adoption of annuity loans, only the remainder of the monthly payment is used for repayment of the loan. The principle will increase over time, while the interest payments will decrease, the net result being that the CAPEX will remain fixed throughout the repayment period. The allowed period or running time will depend on the market conditions, the financing sum, and the risk. Low-risk investments are those that will hold their value relatively well over time, such as property. Higher risk investments are more likely to lose value over time. The exact loss of value is difficult to forecast for the SCCC series.

On the upside, it can be argued that a dedicated container carrier vessel is (almost) optimal for transporting containers now and in the future. Given their optimized hold design, excess fuel costs for spare hold volume and breadth are prevented. On the other hand, the concept vessels focus solely on container transport. If the vessel were to be used for dry bulk shipping, the hold would be non-optimal and therefore relatively less efficient overall compared to general dry bulk vessels. This would then reduce the value of the ship in this scenario. Additionally, the focus on small waterways means that the EoS are limited when used on large waterways in competition with larger vessels. At this point it is impossible to forecast how this equilibrium will work out. The proposed repayment scheme is therefore assumed to be a neutral scenario. Users of the tool can adopt this value to their personal liking, reflecting their own perceived loss of value.

The payback period default can be estimated using Equation 7.5.6 [TU Delft & Nesec B.V., 2014]. The initial investment consists of the SCCC and any potential handling equipment. Free cash flow is the result of net result, depreciation, interest, and principle. If, for example, the SCCC Type 3310 is examined, the investment is ≈ €2.4 million. At 6% interest, the annual CAPEX for an annuity is calculated using Equation 7.5.6 and is also dependent on the payback period. If the loan is repaid in 10 years, the CAPEX is approximately €325,000, and if the profit is assumed to be €25,000, Equation 7.5.6 provides an estimate of less than seven years. Altering interest or profit over reasonable ranges is of some effect. Lowering the interest rate to 2% increases the payback period to 8.2 years. Doubling the profit lowers the period by 0.5 years. Erasing the profit increases the period with 0.5 years. As a result, a default loan repayment period of 10 years is assumed. The effect of the payback period will be reflected upon when discussing the results.

$$\text{Payback period} = \frac{\text{Initial investment}}{\text{Annual free cashflow}} = \frac{€2,400,000}{(25,000+325,000)} = 6.86 years \tag{7.13}$$

$$\text{Annual CAPEX} = \frac{R}{1-(1+R)^{-T}} \cdot Investment = \frac{0.06}{1-1.06^{-T}} \cdot €2.4Mio => \frac{0.06}{1-1.06^{-10}} \cdot €2.4Mio \approx €325,000 \tag{7.14}$$

Result of the 25 year and 75% depreciation is an estimated residual value of 25% of the initial investment upon sale. The vessel at that point is written off for the financial investment. This does not necessarily mean that the life-cycle of the ship is at its end. Depending on the market conditions at that time it could become interesting to maintain operations with the vessel. On the other hand at every moment in the estimated economic life cycle will the SCCC hold a certain second hand value in the market. There can also come a moment where the residual value is greater than estimated and a new SCCC ship becomes interesting. These scenarios will be discussed in the feasibility study which is subject of chapter 10.

7.6. Additional Important Factors

Some additional factors are not necessarily part of any of the previously mentioned cost factors. One of these is the need for sufficient stability. The 2200 and 2300, and even more so the 2300 and 3400, are stability critical, meaning that additional stability may be required. As a result, the following model assumption has been made: the 2200 and 3300 series use 200 tonnes of ballast, whereas the 3400 series uses 500 tonnes of ballast. This ballast is taken when the top layer is used for container loading. The stability calculations justifying this assumption are made and listed in Appendix N.

Another factor is the time and power at an ARA port and inland terminal (IT). As mentioned in Section 2.2, waiting and handling times in the ARA ports are significant. The default value is assumed to be 12 hours.

For the IT, the time is dependent on handling and maneuvering. Maneuvering to and from the terminal is estimated to take two times 30 minutes. Handling time is dependent on the call size and the concept's handling capacity.

Inland vessels do not get fully loaded at a single terminal at an ARA port; instead, they have to collect their cargo at several locations along the port, meaning that additional sailing distance is covered and fuel is spent. The collection distance is estimated to be 40 km per port call.

During the entire round trip, waiting time is likely to be incurred somewhere along the voyage. A two-hour time addition is therefore put in place. This default is however not always correct. Chapter 10 discusses a variation on this default waiting time value.

7.7. Intermediate Conclusions SCCC

This chapter has outlined all of the primary parameters of the SCCC. The SCCC is a small, dedicated inland vessel series created for the transport of containers. The series enables adequate selection of an inland container vessel that is optimized for its task. Other than empty slots when sailing at a loading condition of less than 100%, no excess length, width, and/or draught is incurred. The result is a most efficient IWT solution in terms of the ship's dimensions.

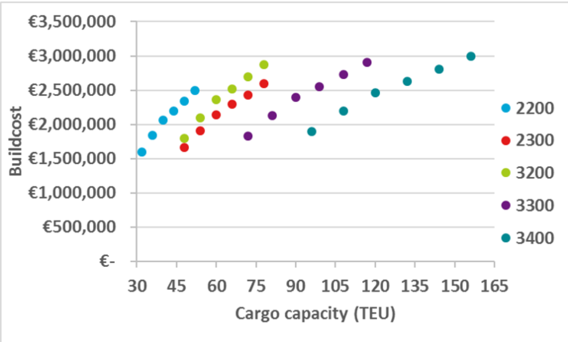
In terms of the different series it is apparent that the difference between a 3210 and 3310, for example, is virtually negligible in terms of investment and operating cost, but the 3310 holds 50% more capacity than thea 3210.

When considering upgrading the 2200 and 3300 series with an additional layer, a problem arises. The 2300 and 3400 series are each 20 centimeters wider than the lower series. In these cases, the ship owner could only choose to invest in a 3400 series hull and operate it with two or three layers at first.

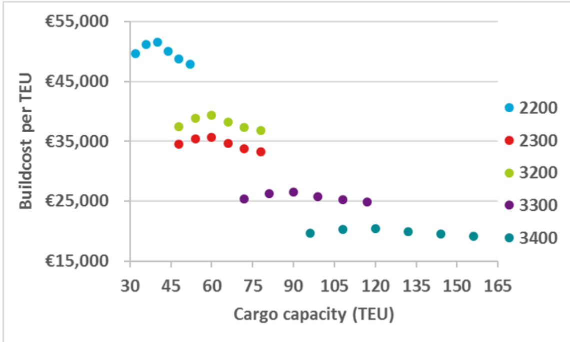
Another interesting result lies in the comparison between the 2300 and 3200 series. These series hold the exact same capacity, but based on a significantly different basis. The 2300 is very small waterway-specific, cannot be upgraded, and is stability sensitive during its operations. Additionally, air draught is an important factor.

A 3200 series, meanwhile, is a full box wider and is therefore less capable of navigating the smallest of waterways; however, it has the capability to increase its capacity over time by 50% by adopting a third layer layout. The 3200 is also a more expensive investment.

The labor costs are dependent on the rules of the CCNR [2016]. The XY10 numbers of the SCCC series all have a length of 86.70 meters, which means that they automatically fall into the highest class in terms of labor force requirements. In practice, a ship owner who orders a vessel will never accept/order a vessel that is just above a certain limit. A ship designer will shrink the total length to 85.95 meters to avoid the requirement of additional labor. For all the calculations regarding capacity, power, and cost the length used will remain 86.7 meters for the sake of consistency. With regard to the labor cost, the XY10 ships are deemed 85.95 meters long and therefore fall into the 70–86 meter labor class. Table 7.5 indicates that the difference between a 85.95 m and 86.70 m under A2 (S1/S2) is around €40,000 per year, adding up to €1 million over a 25-year period. If the fore or aft ship is left unchanged, no additional capacity is gained but these additional labor costs are still incurred.



(a) Build cost versus SCCC capacity



(b) Hull and outfitting cost per capacity unit (TEU)

Figure 7.5: SCCC series results

This entire chapter has been devoted to the development of a dedicated small inland container vessel series. Most of the primary and most important secondary influencing parameters of the SCCC have been highlighted. For the feasibility study conducted later on in this research (Part IV), the costs for all 30 SCCCs cannot be listed for every case or extremity. The author has therefore decided to construct a tool in Excel in which a SCCC database is present that contains all previously made assumptions and reference values so that each SCCC is independently available upon request. This tool contains the defaults and, for many variables, the previously appointed ranges/options, making it possible to study the SCCCs' performance.

Together with the developed SCHC, this enables the inland container distribution concepts to be compared to the current market results presented in Chapter 6. In addition to the OOP expenses mentioned throughout this chapter, the Excel tool also incorporates time, risk and reliability, and overall EC. These additional costs are incorporated for the SCCCs, the SCHC, and several PPH scenarios.

8

Scalable Container Handling Concepts

In parallel with the SCCC of the past chapter, a SCHC has been developed. What is different from the previous chapter is that several concepts are first proposed. These options are compared and ranked in order of greatest potential. The concept that is deemed the best is then fully developed to form the scalable container terminal concept (SCTC).

For this chapter, influences from other logistic fields are used to propose concepts that could be considered revolutionary for the inland container terminal and handling processes. It should also be noted, however, that ARA terminals or existing inland terminals will most likely not accept alternative handling procedures at their quays. Vertical lifting and standard container accessibility are absolute requirements.

Whereas the previous chapter was an extrapolation of knowledge gained in Chapter 3, this chapter focuses on the inventory made in Chapter 5, which established that the market-accepted handling rate lies in the range of €50 per TEU (€83.33 per box). Smaller currently existing terminals require a substantial investment upfront and face high operating costs per box. The only way for existing terminals to lower their operating costs is to grow, and grow fast. Knowing that using current operational practices small-scale inland terminals cannot operate at a sustainable level in the long term creates the challenge of pursuing a low(er) cost inland terminal. The SCHC will thus primarily focus on operating costs.

The concepts are based on existing, proven techniques found in adjacent logistic sectors. Currently, ship-based handling systems are extremely rare in inland shipping. These systems are primarily given shape in the form of a crane , as shown in Figure 8.1a. The main advantage of having a crane aboard is versatility, because it eliminates the need for shore-based equipment. For the present, however, this form of crane concept is set aside, because it is known and has not gained sufficient interest in the previous decade to be adopted by more than a handful of inland vessels.

(a) Inland vessel 'Mercurius Amsterdam' equipped with a crane. Mercurius Shipping Group [retrieved 12/07/2018]

(b) MV Rhine Forest, LASH-carrier, loaded with yellow collared lighters. This vessel is equipped with a gantry crane enabling the (un)loading of lighters aft of the stern. [Seyler, 1998]

Figure 8.1: Two revolutionary concepts that have been build and operated

Chapter 5 highlighted multiple options for potential improvements. A parallel system that forms a continuous handling process could be considered. Loading, unloading, terminal transport, and storage that are all performed simultaneously can lead to faster handling. Another improvement could follow a batch loading principle that requires fewer moves for the same call size. As a result, the time the ship owner spends at the terminal is reduced. Part of his/her gain can than be recouped via higher tariffs, leading to gains for both the terminal and the ship owner. Additionally, a terminal that is closer to the destination might be able to operate more slowly as long as its GC is competitive. Chapter 5 has also demonstrated that moving equipment is very expensive. Splitting the wide-span gantry crane in a fixed ship-to-shore and movable stacking crane might also be an option to increase the speed and reduce the cost, because the equipment can become more simplistic.

Section 8.1 outlines the first terminal concept based on a rolling conveyor concept (RCC). The ship-to-shore handling, terminal transport, and storage facility are each discussed in separate subsections. The next concept focuses on a faster handling principle. Stacked containers on (linked) carriages could potentially lead to fewer moves per berthing for the same call size. The carriage loader concept (CLC) is the subject of Section 8.2.. The third concept is based on another fast container stack handling system referred to as the “X-pack.” Section 8.3 explains this concept, which could be considered the vertical equivalent of the carriage concept from Section 8.2. The fixed ship-to-shore crane concept is explored in Section 8.4 in order to determine how a fixed version of the wide-span gantry crane would operate.

The best or preferred concept is selected by weighing the concepts in Section 8.5. First, the individual criteria and their weight factors are discussed, after which the selection is made. Section 8.6 then explores the best or preferred concept in greater detail. These details are then used in the feasibility assessment that is the subject of Chapter 9.

8.1. Rolling Conveyor Concept (RCC)

This first concept follows the principle of gliding movement. In parcel logistics, parcels are handled as few times as possible. All movement takes place on gliding rollers, which help to split and join cargo flows. This section consists of three subsections describing the individual parts of the handling process.

8.1.1. Hatch Coaming / Gangway Gantry Crane (HCGC)

The first concept is an evolution of exiting technique. Many vessels make use of hatch covers, which are opened and closed by hatch cover cranes. These cranes ride on tracks attached to or on top of the hatch coaming. The current application is relatively lightweight, since these hatch covers weigh in the order or hundreds of kilos . A more heavy-duty application has been found in the lighter aboard ship (LASH) concept. Figure 8.1b shows the LASH ship Rhine Forest, which used an extremely heavy-duty application of such a crane.

Figure 8.2: Example of an existing hatch cover crane [Blommaert, retrieved 12/10/2018]

The main advantage of this concept is the possibility of presenting and/or receiving the container at every location along the hold. With fixed quay equipment costs can be significantly reduced. The HCGC concept could be designed to ride on either the coaming or the gangway; there is virtually no difference in terms of the cost or workability.

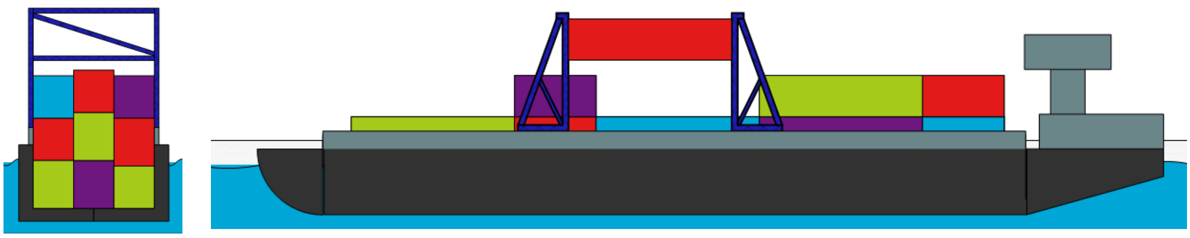
The air draught of a high piece of equipment is crucial at inland navigation. As a result, the gantry should be foldable/retractable/lowerable to prevent additional air draught. In the operational configuration, the gantry should be high enough to move the container above and beyond the other stacks. Strength-wise, the maximum container weight was found to be 32.5 tonnes in Chapter 4. The HCGC should therefore have a minimum carrying capacity of 35 tonnes.

Containers aboard vessels are stored lengthwise, which provides two options for unloading. A container can be unloaded parallel to the quay, which requires two cranes, one at either end, to lift and move the container. Another option would be to rotate the container 90 degrees so that the HCGC can have limited size . Since the HCGC moves across the hold length only, distances are limited. The low height results in short hoisting and lowering distances. Overall, the moving distances are short, which could lead to a relatively high handling capacity per time unit. Since the SCCC vessels have beams varying from 7.0 to 9.5 meters, rotating a 40 or 45-foot container with a single piece crane is impossible. A parallel HCGC consisting of two pieces is therefore necessary.

Stability could become critical when lifting heavy containers and moving them along the vessel. In addition to the container weight, the HCGC's own weight will also negatively impact the stability. An active ballast system could ensure sufficient stability at all time. Given the crane vessel of Mercurius Shipping Group, a workable stability solution should be achievable. The stability calculations of Appendix N found minimal available excess stability.

The movement to and from the vessel can occur in two different ways. Either a ship-bound crane reaches over the quay, or the quay equipment reaches over the vessel. This second option is adopted in the form of a moving table on top of a quay platform. Figure 8.4a demonstrates how the table should move. Since containers are 2.5 meters wide and the quay wall gap is assumed to be 1.5 meters, the sliding table should slide out at least 4 meters. In the case of a ship-bound system, the chosen equipment would be far more complex and heavy, and stability would be even more of a concern.

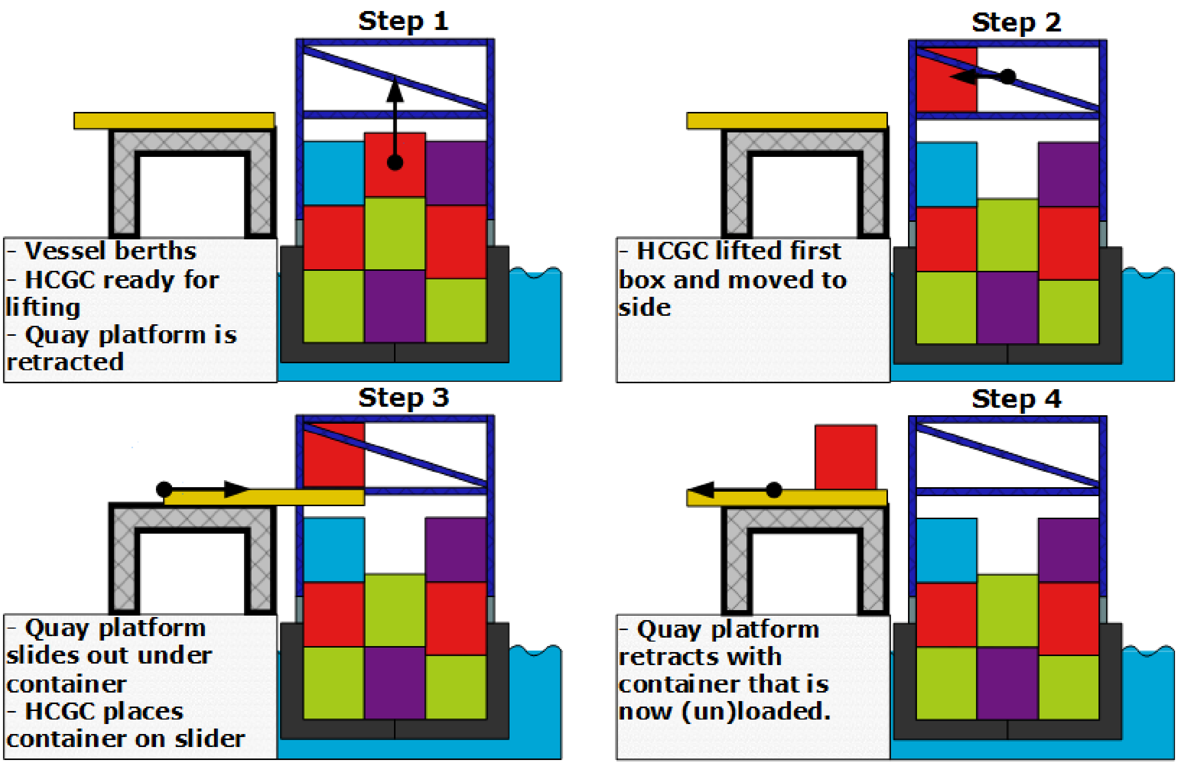
Lowering the HCGC by a foldable design will not be durable and will compromise the HCGC's strength. The author therefore proposes building an additional piece of hatch coaming at one or both ends of the hold that could be lowered into the double-sided hull. These two parts have to be lowered just far enough to fall within the vessel's own air draught. Regulatory limitations for free visibility are considered outside of the scope of this thesis, but at the same time, the equipment's presence is assumed to be acceptable.



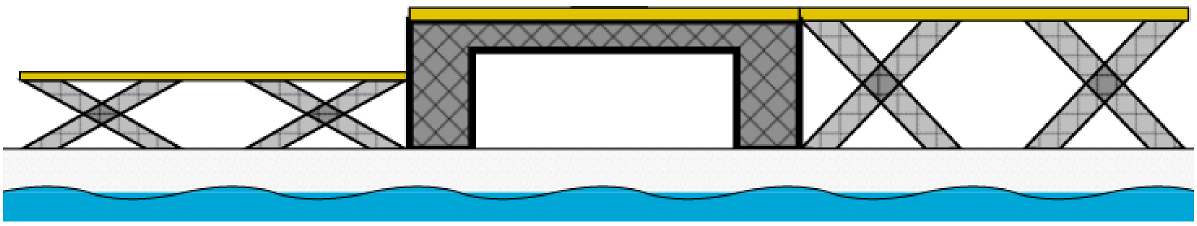
(a) Front view (b) Side view

Figure 8.3: Hatch Coaming Gantry Crane Concept (HCGC) [source = own work]

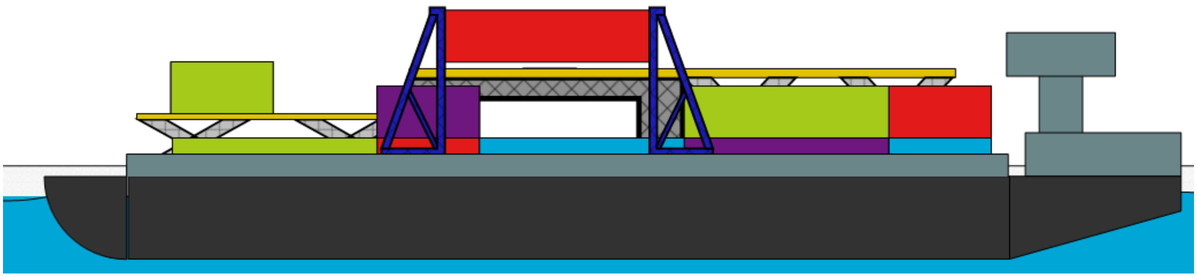
The ability to move containers across the vessel means that a fixed land connection with a crane or rail is possible. This can be expected to cost significantly less than moving equipment such as a wide-span gantry crane. A shore-based receiving rail/conveyor belt system that is fixed and that only has to move vertically will costs hundreds of thousands of euros, while a wide-span gantry crane costs approximately €4 million [Ligteringen and Velsink, 2012].



(a) Overview of loading procedure. [source = own work]



(b) Side view of shore equipment [source = own work]



(c) Side view of HCGC in action [source = own work]

Figure 8.4: Overview of RCC parts. Yellow indicates rolling conveyors. Coloured rectangles are containers.

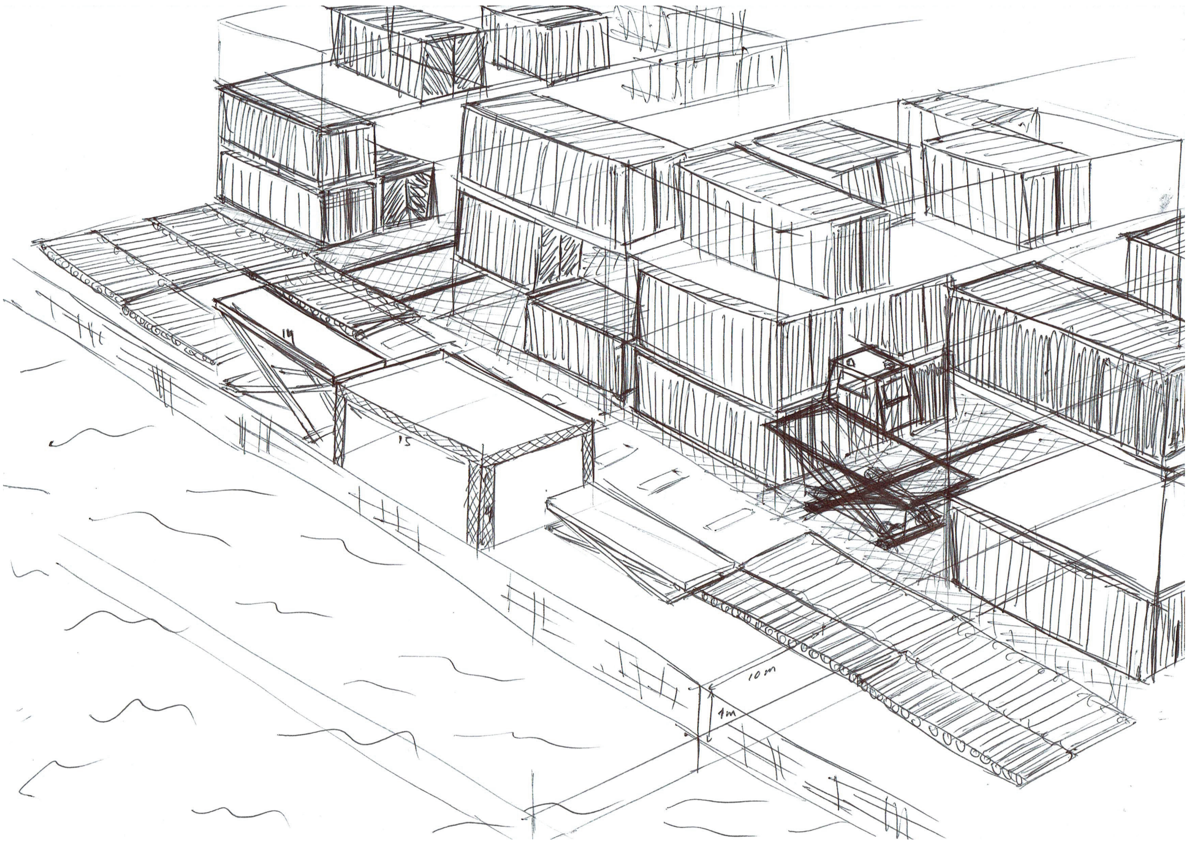
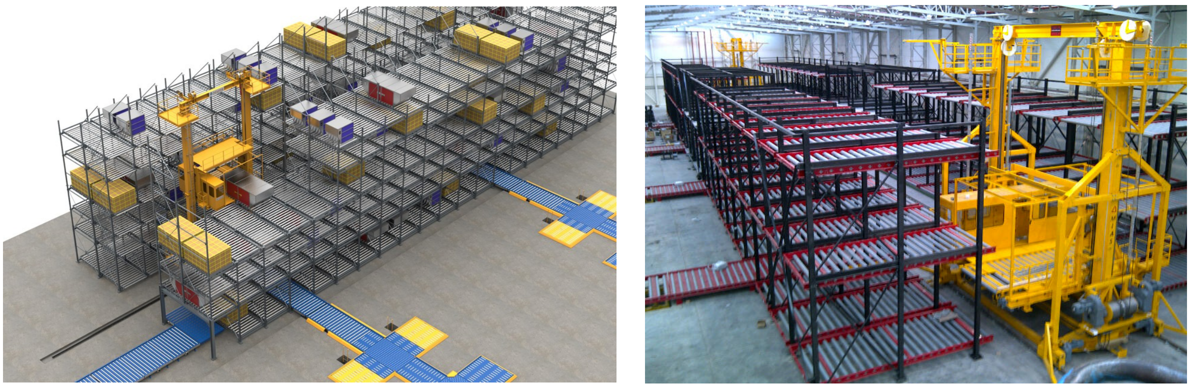


Figure 8.5: Artist impressions of quay side terminal area. [source = own work]

8.1.2. Rack System

The first storage concept makes use of a rack system. Figure 8.6 shows examples of the storage of unit loads used in airfreight transport. Although airfreight crates are lighter than deep-sea containers, the concepts should be relatively easy to upgrade for larger weights and higher loads. The systems shown can already bear up to 7 tonnes per 10-foot load.

Airfreight crates cannot be stacked; therefore, they require a separate stacking solution. The main advantage of this storage technique is the superior accessibility of stored unit loads. When the elevating transfer vehicle (ETV; i.e., the yellow piece of equipment in Figure 8.6b) retrieves or places a unit load, no other loads have to be moved if only one unit load is placed in each bay. When 45 ft. deep bays are used, a maximum of two TEUs can be stored in each bay, requiring a maximum of one additional move.



(a) Artist impression of air freight terminal for the Nairobi Airport [HSS, 2017]

(b) Baku Cargo Terminal 20ft Elevating Transfer Vehicle [BDP, retrieved 13/07/2018]

Figure 8.6: Examples for the storage of unit loads in air freight terminals

This storage type is easily scalable since either the length or height of one ally can be changed. For the required area per TEU great storage density can be achieved. With a 45 ft. deep bay at both sides and a slightly wider central ally, the floor space required is roughly 132 square meters. With stacking as high as four levels, eight 40-foot/45-foot or 16 20-foot containers can be stored. At 16 TEUs per 132 m^2, the average density becomes 8.25 m^2 per TEU. If 20/40 foot-specific [1] racks were to be built, the density would increase to 7.5 ^{2} per TEU. This results in a density equal to a 4-high stacking gantry crane that is a.o. used for its superior dense stacking but lacks the accessibility the rack system could offer. A top view of a possible container rack solution is provided in Figure 8.9.

$$\text{Floor space per allay with rack at either side} = \text{Width} \cdot \text{Length} = (2 \cdot 14(\approx 45") + 16(\approx 53")) \cdot 3 = 132m^2$$

The exemplary RCC terminal illustrated in Figure 8.9 has a total area within the perimeter of 1 hectare or 10,000 square meters (rounded up). The racks are 40 ft. long, thus allowing for two TEUs per bay. With four rows of 16 bays per row, the terminal can store up to 128 TEUs per layer. When a three-high racking system is used, a total of 384 TEUs (230 boxes) can be stored; four high would create a capacity of 512 TEUs (307 boxes) for a FEU/TEU ratio of 1.67.

The storage area itself is approximately 50 meters by 85 meters. The three-layer layout would then have an effective stacking density of 11.07 m^2/TEU, and four layers would theoretically reduce this even further to 8.3 m^2/TEU.

The rolling systems are relatively vulnerable to weather influences in inland terminal applications. At airports the freight terminals are covered, which eliminates the weather impact. A system such as this would therefore require more substantial repair and maintenance. In an industrial setting, however, these systems are expected to be made robust, which would reduce the breakdown, and therefore the downtime, to an acceptable minimum. Instead of metal-on-metal with steel rollers and containers, a solution is proposed consisting of a set of supporting rubber or hard plastic wheels. This is discussed further in the next subsection.

On the investment side, the racks are relatively low-cost and low-tech. The ETV is the main moving piece of equipment. Since it is rail mounted, robust, and performs simple movements, the price of this piece of equipment is estimated to be in the same region as, for instance, a reach stacker. Automation of this equipment is simple and therefore low-cost. The sliders are equally simple and are therefore also relatively cheap. Managing the overall terminal with all of these systems means that ICT expenses will be higher than on a regular terminal.

The Achilles' heel of this system also lies in this storage type. When the ETV and/or bay slot conveyor breaks down, a standard crane cannot reach the containers. Staying operational under these conditions could be very difficult. The dependency on fully operational equipment is high. A wide-span gantry crane terminal, however, is equally dependent on its equipment and is widely used. This should therefore be viewed as an important factor, but not as an insurmountable problem.

Examples of failures that could occur include loss of operation of the ETV, damaged containers due to misalignment, and containers jammed in the rack. When the terminal is unmanned and/or autonomously operated, a jammed container may mean that the container cannot be transported on time. This will lead to claims and unhappy terminal user(s) and will eventually reduce the terminal's attractiveness.

Figure 8.7: Example of a multilevel rolling conveyor system [Conveyor Handling Company, retrieved 16/07/2018]

[1] The racks plus allay would than together be 40 metres instead of 44 metres.

8.1.3. Gliding System / Rolling Conveyor

In conjunction with the proposed rack system, a container transport system for all container movement between the landside, storage, and quay areas is proposed. Current logistic solutions in lighter freight are used for this system. At parcel logistics and baggage systems, for example, the contents are transported on gliding roller systems. These rolling conveyors provide heavy-duty movement and are currently used for loads as various as air freight containers, pallets, and smaller packages/parcels. As with the rack system, this principle is easily scalable. Figure 8.7 provides an example of a rolling conveyor system in parcel logistics.

Advantages of a continuous system include the fact that the equipment is not busy with one piece at a time. With a conveyor system, multiple containers can constantly be moved. The movement does not occupy cranes at either end, increasing the throughput capacity. Additionally, for the inland terminal, all possible movements are known. Free-moving equipment is therefore slightly overcomplicated for what is actually demanded from a process perspective. Sliding is also a safe handling method for the contents of the containers, eliminating accelerations/decelerations when picking and placing the boxes.

Regular containers are not designed to roll on any surface; therefore, a support plate with stacking cones at the corners is used. These baseplates could, for instance, be made in such a way that support every 2 meters would be sufficient. This would significantly reduce the cost and number of moving parts. Five rows of supporting wheels would be used for a baseplate 2.5 meters in width and 12.5 meters in length. If these wheel rows consisted of six wheels spaced 40 centimeters apart, there would be 30 wheels offering support at all times. With a maximum container weight of 32.5 tonnes and around 1 ton per plate, the wheels would each have to support just over 1 ton.

The gliding system could be made in such a way that minimal energy would be required if the terminal grew and significant distances had to be covered. When the containers are unloaded, the vertical movement from the highest lifting point to the ground could be eliminated by installing a receiving platform above the ground. By using a lifted platform the HCGC can be made simpler, reducing the cost and increasing the reliability of operations. Figures 8.4b and 8.4c provide an example of how the quay equipment might look.

The containers could be moved from the receiving platform to the stacks using a sloped conveyor. There are, however, two problems with this idea: a steep slope would lead to uncontrollable container behavior and might be harmful to the container's internal cargo. Braking the container would be difficult requiring complex construction, and in case of slippage, the container's contents would most definitely be destroyed. On the other hand, a very limited slope would mean that the length increases substantially beyond the required terminal dimensions. Overcoming a 5-meter height difference at a slope of 2%, for example, would result in a slope length of 250 meters. Looking at the terminal design provided in Figure 8.9, this length is 2.5 times the largest distance present. This would likely cost more in additional conveyor material and required area than the reduced energy consumption could make up for. Using a single degree of freedom elevator would enable the most efficient lifting and lowering of containers. During the lowering of heavy incoming containers, it may even result in possible energy recovery that could (partially) be used to lift outgoing containers. Containers from the stack are then raised on the other side at a separate platform so that they arrive at the loading platform height. Since the quay platform is large enough to store two containers side by side, parallel operations are possible. When an unloaded container moves to the right onto the scissor lift, a container ready for loading can be slid simultaneously on the quay platform. Figure 8.9 illustrates how this operation could take place. In the long run, this concept is expected to succeed since the terminal can stay small. This eliminates the need for long-distance internal transport, thereby increasing the terminal efficiency.

The primary strength of the rolling conveyor concept lies in its continuous operation. The landside and quayside are connected via one or more ETVs, but can both be operated individually. As the layout shows the terminal is easily scalable, meaning that minimal costs can be achieved at all times . The dedicated track allows for automation and unmanned operations that are relatively easy to implement. In the long run, this will lower costs and provide a future proof design. Since all of the pieces have been optimized for their own purpose, the equipment costs are assumed to be relatively low due to the reduced complexity.

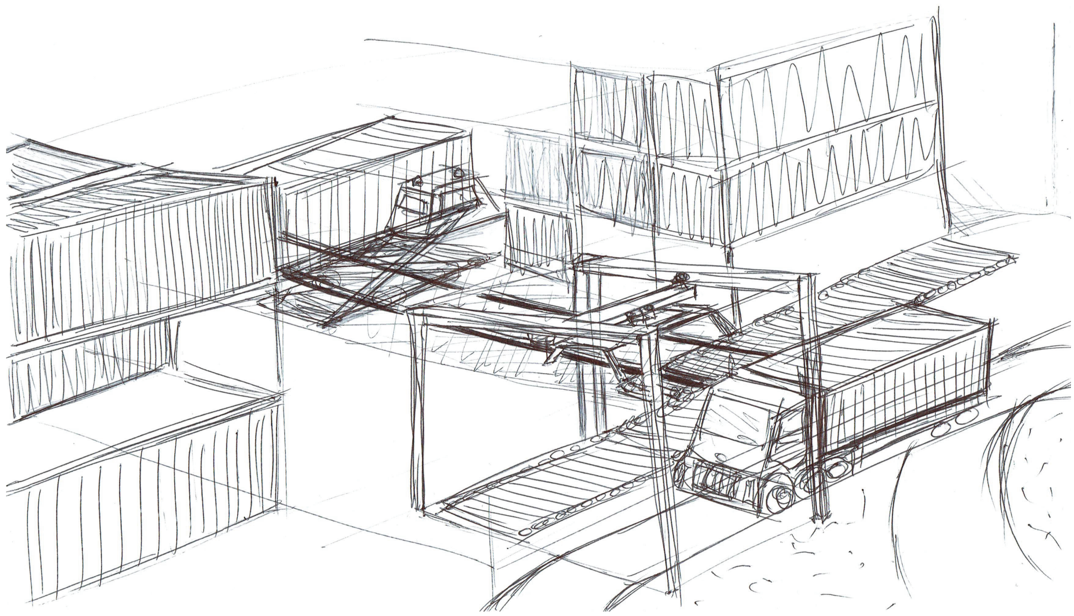


Figure 8.8: Artist impressions of land side terminal area. [source = own work]

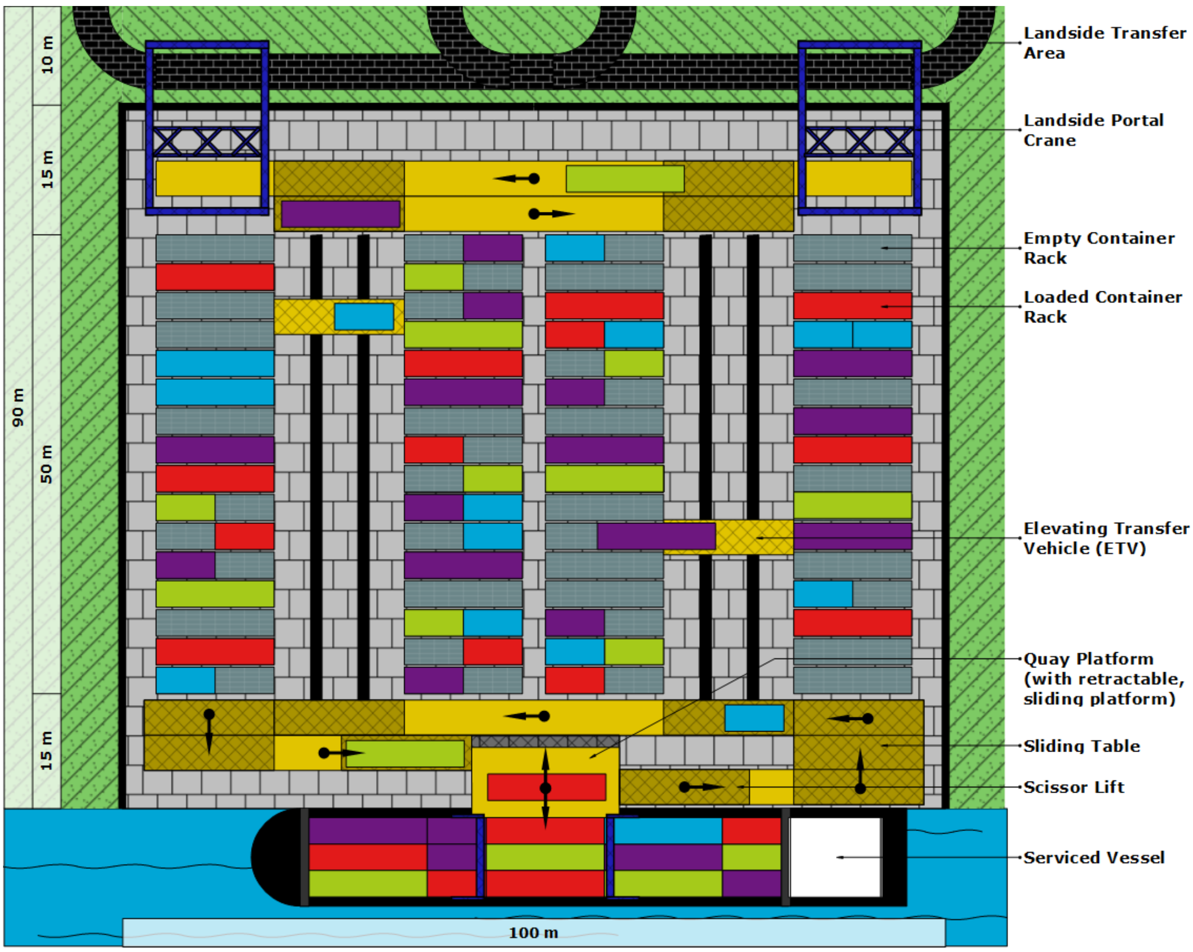


Figure 8.9: Top view of yard layout providing an overview of the RCC parts. The storage capacity is 128 TEUs per layer. Yellow indicates rolling conveyors, colored rectangles are containers, grey rectangles represent available storage slots, and striped boxes are sliders or scissor lifts used to change the containers' direction of travel [source = own work]

8.2. Carriage loader concept (CLC)

The second concept does not focus on parallel, continuous operations, but rather on batch (un)loading of cargo, which means handling multiple containers rather than one box per move. Moving an entire container stack at once creates the possibility of handling multiple boxes per move. The principle this concept is based on is that although the time per move might increase, the number of containers per move increases even more, outweighing the additional time and resulting in an overall shorter handling time. This batch style can occur via either vertical or horizontal movement. Horizontal movement is the basis for this concept discussed in this section. Vertical movement is the subject of the next concept, which is discussed in the next section.

By loading (coupled) carriages, a similar gain can be achieved to that which led to the adoption of containers. Whereas individual boxes or bags used to be loaded, the container enabled mass handling because all boxes/bags where contained and could be handled as one unit. Bundling containers onto a rolling carriage is one step past the containerization of goods. The bundling of individual containers allows them to be handled as one.

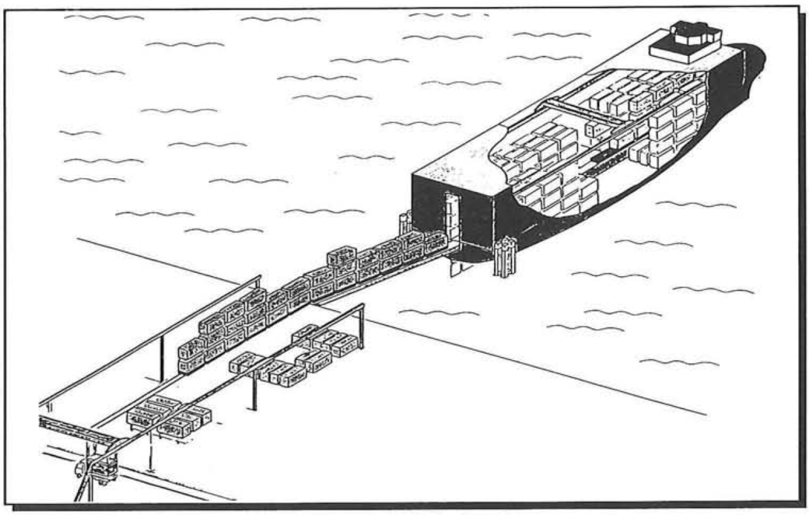


Figure 8.10: Train loader concept. Short-sea loading concepts from Wijnolst et al. [1993]

8.2.1. Train and/or Carriage Loader

The train loader concept illustrated in Figure Wijnolst et al. [1993] is a short-sea oriented concept created by8.10. For inland shipping, this application would mean very fast (un)loading, since the number of trains an inland vessel carries is limited as a result of the limited vessel dimensions. With respect to the vertical lifting and accessibility requirement, the trains should carry all containers in a single stack. Placing tweendecks to accommodate multiple trains on multiple levels would prevent accessibility from above, which excludes this option. Having removable tweendecks would require many additional moves by cranes that in turn nullify the gains achieved by using the trains.

For inland shipping, the train loader application is unsafe because of stability limitations. In the case of two or three-container wide storage, as was scoped , either 50% or 33% of all cargo would be (un)loaded at once when a full train was moved. The stability of inland container vessels is always a point of concern, as Appendix N indicates. Such significant changes in loading degree are impossible to accommodate even with active ballast in combination with relatively fast handling. An active ballast system that could counter this impact will require many hours of ballasting since both sideways stability and trim will inevitably be of concern. The result is that only two or three trains are (un)loaded, but with intervals of hours in between. (Un)loading means that the train is slidden out very slowly while at the same time the vessel is ballasted with great care.

Having stacks stored on individual carriages similar to MAFI 's in RoRo shipping might form a solution to reduce the impact of changed loading conditions. Handling complete carriages would lead to faster handling. The downside, however, is that only entire carriages can be removed at once. If only one or two containers of a triple-stacked carriage need to be unloaded, the carriage itself must still be unloaded . Onshore rearrangement of the carriage is required before the carriage can be loaded again. In these applications, inventory management becomes critical.

Another bottleneck is the (un)loading of carriages. The most obvious solution would be a stern ramp allowing carriages to roll in and out over tracks. This would be technically demanding but could be feasible. The primary shortcoming of this vertical solution is that the carriage accessibility is highly limited. To handle containers placed near the front of the hold, all carriages between the aft and front have to be removed. This makes handling cumbersome and critical . On a fixed trip between two points, the vessel would be unloaded entirely at either end. In a round-trip scenario, either the carriages stored near the bow would have to be unloaded at the first stop and reloaded at the stern, or all of the carriages would have to be unloaded at the destination of these remaining carriages in order for them to be reachable. Additional handling is therefore required, costing valuable time and money.

A great advantage of using carriages is the movability of the stacks once free. Unloaded stacks can be driven across the terminal. New carriages can be preloaded on the shore so that when the vessel comes alongshore the carriages can quickly be loaded as a whole. How these carriages are handled is complex in two ways. First, the loaded carriages are heavy, requiring substantial power to move them. Self-powered carriages are probably too heavy and complex, but small trains are a potentially costly investment and bottleneck. The capacity is directly dependent on the number of assisting trains. On the other hand are unloaded container carriages not fully handled. The container stacks still require individual handling for the removal and stacking of containers. The next subsection provides a solution to this handling problem.

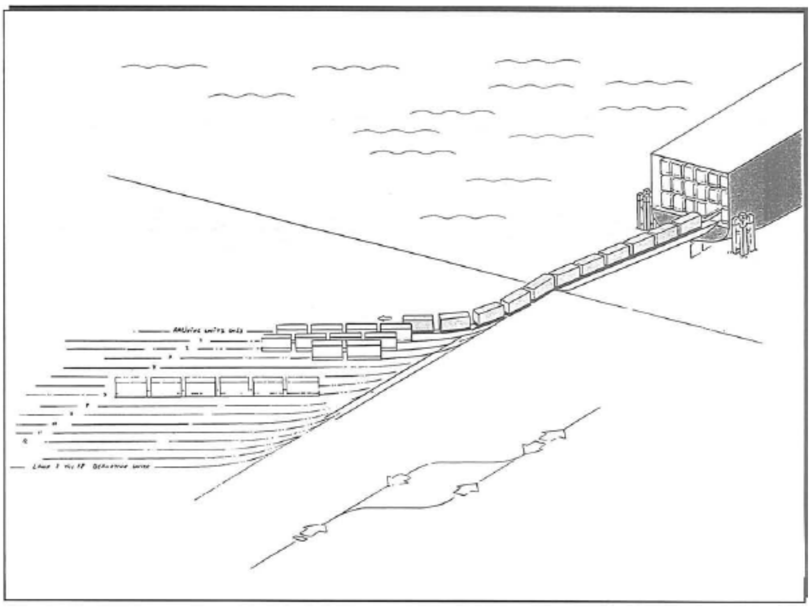


Figure 8.11: Train carrier concept. Short-sea loading concepts from Wijnolst et al. [1993]

The concept by Wijnolst et al. [1993] involves a ship being moored perpendicular to the quay (see Figure 8.11). For a small inland waterway, this method is virtually impossible due to the narrow waterways. Digging a recess to accommodate a vessel is a costly investment, and manoeuvring would be time consuming and difficult.

Berthing a vessel almost perpendicular to the quay could be a solution. The result is that additional quay length is required, which comes at a cost. The need for additional quay length also limits the number of possible terminal locations.

Keeping the investments in mind, it is apparent that far-reaching crane equipment is made obsolete, making that costly investment unnecessary. Hauling equipment for the (un)loading procedure can be relatively cheap but slow when a central winch-like system is used. Self-powered carriages become expensive, especially given the number of carriages required along the system. For example, a heavy-duty version of an Automated Guided Vehicle (which according to Rademaker [2007] cost €400,000 in 2007) could cost €500,000. A 2-TEU wide, 10-TEU long vessel would then require a 10-FEU sized carriage, requiring at least €5 million of investment in carriages. This is many times greater than the investment the entire vessel demands.

When the vessel is larger and/or the carriages are also used at the storage location, even more carriages are required. Simplistic carriages are therefore the only possibility. The cost of a standard train carriage, for instance, was estimated at €50,000 by Van Dorsser [2015]. A heavy-duty version allowing stacked containers would then cost at least €100,000. Operating the carriages and/or trains in order to move these containers would be quite cumbersome and labor intensive. Automating such a system would be very complex and therefore expensive.

In addition to the carriage and hauling equipment, the need for tracks also results in substantial investment cost. Scalability is also difficult because more rails and junctions are required. The investment in track and strengthening the site should be considered sunk or irrecoupable cost, [2], meaning that if the terminal turned out not to be profitable in practice, these costs could not be recouped.

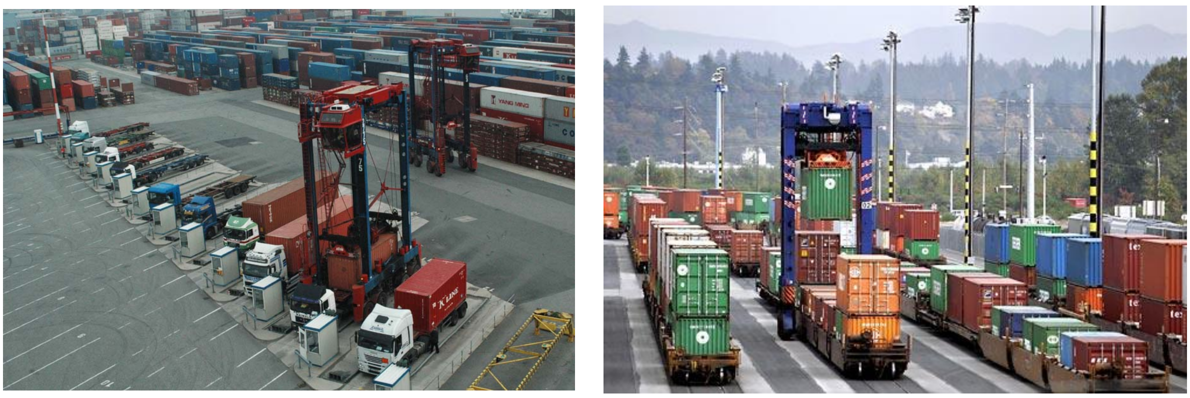
The train loader is expected to be complex, and the result of complexity is almost always a high cost. In this case, is the train loader is also expected to be expensive. Additionally, automating this process will be very difficult given current technological capabilities.

8.2.2. Straddle Carrier

Handling the carriages and therefore containers could be done with help of a straddle carrier-like concept. Irrespective of its loading condition, a truck enters a landside berth. When the driver locks in at the location, a straddle carrier comes and drives over the truck so that it can either place or take off a container (see Figure 8.12a). It then retracts so that the truck is cleared again and can leave the berth. The straddle carrier can then drive over the to-be-prepared carriages for (un)loading (see Figure 8.12). When containers are stacked three or four high on a container carriage, the straddle carrier should be one higher. Current carriers hold a maximum capacity of one-over-three HCs, meaning that they can lift one HC container over a stack of three HCs. Of course, they also have some additional room for movement, thus maximizing at a carriage + 4 HC containers stacked on top . This is under the assumption that the carriage is a maximum of half a meter high. The straddle carrier, however, is therefore very large and expensive.

The investment cost of a straddle carrier lies between €700,000–€800,000 with annual R&M of 7–8% of the investment cost [Rademaker, 2007] [Naicker and Allopi, 2015]. Highly skilled personnel are also required [Ligteringen and Velsink, 2012]. Automation could be deemed currently economically impossible at a competitive rate for small-scale inland terminals. A reasonable operating speed would require more than one carrier, leading to substantial equipment cost and even more drivers. The investment costs are not so critical because they can be spread over a long period, but R&M and labor could put pressure on cash flow and liquidity.

Stacking density by a straddle carrier is high (see Table 5.2); however, for a low cost, rural terminal ground should not be expected to be that expensive. Storage density performance then becomes less important.



(a) Straddle carrier (un)loading trucks with containers [author = unknown, retrieved 16/07/2018]

(b) (un)loading carriages with stacked containers in the Port of Tacoma, USA. [Ringman, 2005]

Figure 8.12: Possible operations for a straddle carrier based concept terminal.

[2] Sunk cost are in economic perspective costs that have been made and that cannot be recovered.

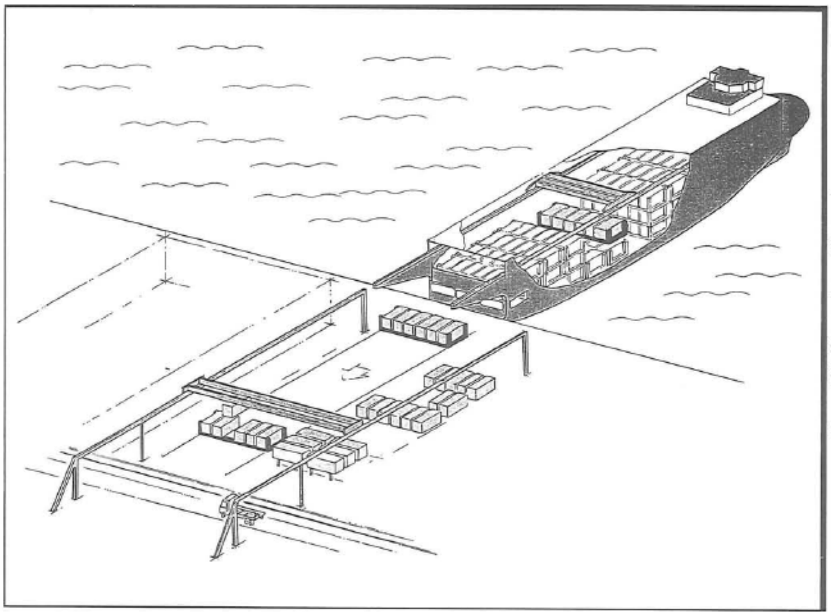


Figure 8.13: Six-pack cradle carrier concept. Short-sea loading concepts from Wijnolst et al. [1993]

8.3. X-pack Concept (XPC)

The XPC is also based on the work of Wijnolst et al. [1993], but it focuses on vertical batch loading. Although the concept dates from 25 years ago, this does not necessarily mean that it is not of interest. Twenty-five years of progress may result in current feasibility. A super pallet or pack consisting of “X” number of containers could be used to (un)load. Although the speed per move is lower, the capacity to move multiple units at once might make the overall speed relatively high. X-packs can take shape in the form of entire stacks or even multiple stacks. Given the container weights, a 20-foot four-pack could weigh as much as 120 tonnes (excluding the x-pack cartridge 's own weight). Packs or pallets consisting of multiple stacks could weigh even more. The result is that handling becomes heavy lifting, requiring additional attention. A movable crane performing these operations will be very expensive and therefore not feasible. Working with a fixed, heavy-duty crane is estimated to be both technically and economically plausible, but challenging. A ship-to-shore (STS) crane like those used at the deep-sea terminals is estimated to cost €4.5–€7 million (base year = 2007) [Rademaker, 2007]. A market analysis by Achterberg [2012] has indicated that costs had already increased to near $10 million or €7.8 million in 2012. These cranes are massive in size, however, and far larger than required for the SCCC vessels. For example, an inland outreach of 15 meters instead of the deep-sea range (40–65 m) should suffice. Similarly, the height, back reach, and speed could be reduced to their appropriate levels. As a result, the cost of such a crane is therefore estimated to be at least €2.5 million for the year 2018.

On a large deep-sea carrier, the effects of removing 100 tonnes in one move might be minimal. For inland vessels, the impact is far more significant. For the SCCC-type 2208, for example, this could mean a 5% change in the current displacement. At a draught of 2.5 meters the vessel will then rise approximately 10-15 centimeters. Additionally, trim could change significantly, and stability would become critical (again, see Appendix N for stability calculations).

Whereas the (un)loading procedure might become more efficient, the pack requires additional handling on-shore. The pack requires (un)packing, which leads to a second (un)loading procedure cycle. Additional dedicated equipment is required for this procedure, or the very expensive, heavy-duty crane should perform these operations. Making the moves with this movable piece of equipment would be very inefficient since only one in every “x” moves requires its full potential. Separate container moves do not require this capacity, meaning that cheaper and simpler equipment would suffice.

This concept has superior handling capacity characteristics in terms of speeds and ease of use. Since speed is not as important for small-scale inland shipping (SCCC = max 156 TEUs), this concept would work better at deep-sea terminal operations where 10,000+ TEU vessels are handled. The need for heavy-duty equipment with the capability to lift 100 tonne weights is not in keeping with the goal of a low-cost, simplistic inland terminal design. As a result, it is safe to conclude that for small-scale inland shipping STS hoisting operations, no significant changes can be made other than cheaper versions of current equipment. It can therefore be concluded that for small-scale rural applications, the time value is ≤ the cost of the additional handling speed.

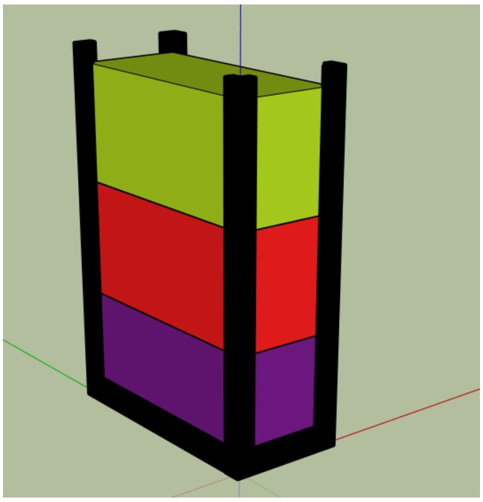


Figure 8.14: Example of a 3-pack system. Containers are loaded and secured in a cartridge like system. [source = own work]

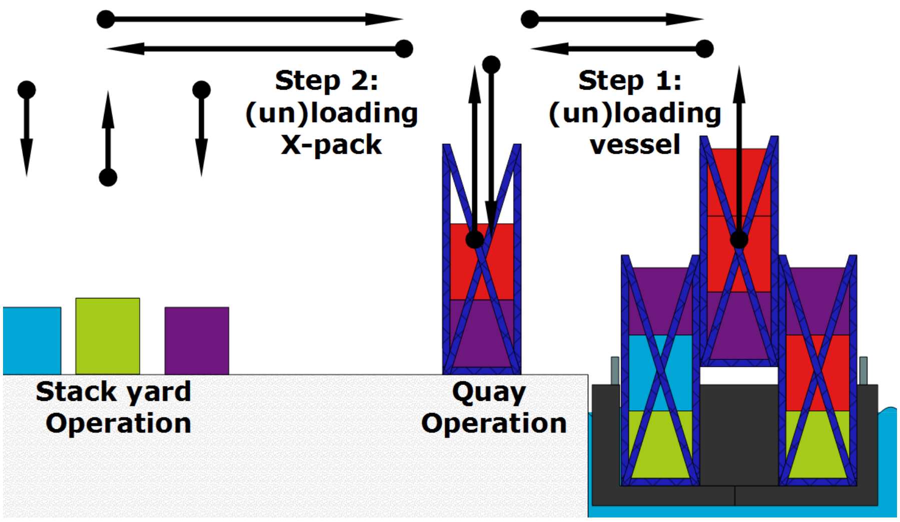


Figure 8.15: Unloading example for a 3-pack system. Reverse will be loading principle. (side view) [source = own work]

The fixed shore crane used to handle the X-packs is only one piece of the required equipment. A rail-mounted or rubber tire gantry crane or reach stacker could be used for storage purposes. This equipment could also be used to (un)load the packs. The result is that a very expensive piece of equipment would be added to the terminal without saving or excluding any other equipment. Handling costs would therefore rise. The call duration for a vessel would be shortened, however. It is important to find a point at which the time gain justifies the increased terminal costs. Current terminal layouts do not use this type of concept, which should be considered as an indication that the point of time versus cost does go more towards cost than time. Figure 8.15 illustrates the two steps of handling a vessel loaded with X-packs. Loading and unloading could be referred to as Step 1, while Step 2 involves packing and unpacking the X-pack.

8.4. Fixed Ship-to-Shore Crane (FSSC) Concept

Wide-span gantry cranes are currently the most common terminal equipment (see Chapter 5). This expensive piece of equipment offers an all-in-one solution for a small-scale terminal design, but it is also likely to cause a bottleneck. This is similar to the dangers current wide-span gantry crane terminals face when they are relying heavily on their crane, which can handle one box at a time and therefore either operates at the quay, the stack, or the landside. The freedom of moving the crane comes at the cost of requiring a human driver. The movability ensures that the crane spans the served ships, the stacks, and the landside transfer zone when required. This concept therefore focuses on the application of splitting this functionality into its separate pieces in order to determine whether the sum of the parts is better or worse than the individual sub-processes

8.4.1. Fixed Crane

Operating a fixed overhanging crane takes away the crane's functionality of spanning the entire hold. As a result, the ship must be moved during its terminal call to let the crane access all slots. In this case, efficient load planning is required; otherwise, the entire ship has to be moved frequently, costing valuable time and effort that translate to cost.

The resulting concept is based on the design of the Dutch advisory company Koch Adviesgroep [retrieved 02/07/2018], which has designed a full inland terminal concept called the New Generation Integrated Container Terminal (NGICT). Their study has claimed economic feasibility for a throughput of 20,000–40,000 TEUs/year. Whether or not this is worth pursuing for a ≤ 20,000-TEU inland container terminal is interesting enough to research; however, since their results are classified, this claim cannot be verified. Figure 8.16 provides some computer-generated images from the concept.

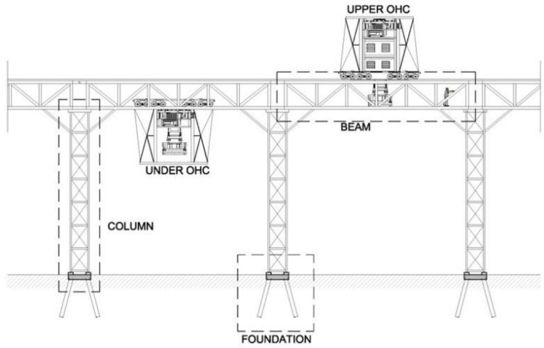
The main advantages of this type of "fixed" crane lies in its space requirement and handling capacity. Compared to a wide-span gantry crane, however, this fixed NGICT loses one direction of travel. It can no longer move parallel to the vessel. Unloading requires the vessel to move forwards and backwards since the overhead rails and supporting structure are fixed. The rails can also be elongated fairly easily, ensuring scalability. A second (or more) lane(s) alongside the first is also an option, as demonstrated in Figure 8.16d.

Compared to a traditional gantry crane that uses one running trolley per rail , this concept can accommodate multiple OHCs. The design incorporates two or even three overhead cranes (OHCs) running along the rails. Upper and lower OHCs can pass each other even when loaded, increasing the operating speeds significantly. Figures 8.16a, 8.16b and 8.16c illustrate the moves of the overhead cranes. During the startup phase of the terminal one could begin with one OHC and add additional OHCs when the throughput volumes allow for additional investments and/or require higher handling speeds. Since the infrastructure (the rails) is already present, the additional cost apart from the investment in an additional OHC is relatively low.

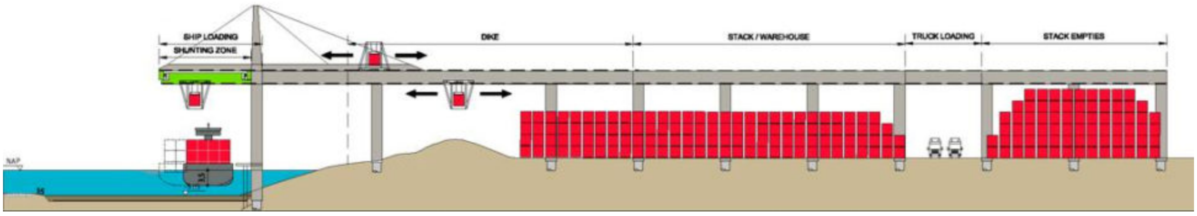
Compared to a fixed quay crane and reach stacker terminal Koch Adviesgroep [retrieved 02/07/2018] has stated that the NGICT can operate in one third of the space. In comparison with rail-mounted gantry cranes, the NGICT can operate in as little as 46% of the space . The OHCs can perform STS handling, stacking activities, and landside transfers. It can therefore offer services similar to those of a wide-span gantry crane but at a greater service level and, presumably, a lower cost. Additionally, because only the OHC is moved rather than an entire gantry crane, energy consumption is far lower. On average, an OHC moves a sixth of the weight of a large wide-span gantry crane.

Also pointed out at the straddle carrier in Subsection 8.2.2 is the superior stacking density not of primary concern at a more local, small-scale application. Building a large facility along the shore of the Rhine near a large city may result in high ground prices and/or site scarcity. For this application, however, such challenges are not expected and thereby (almost) nullify this superior capacity.

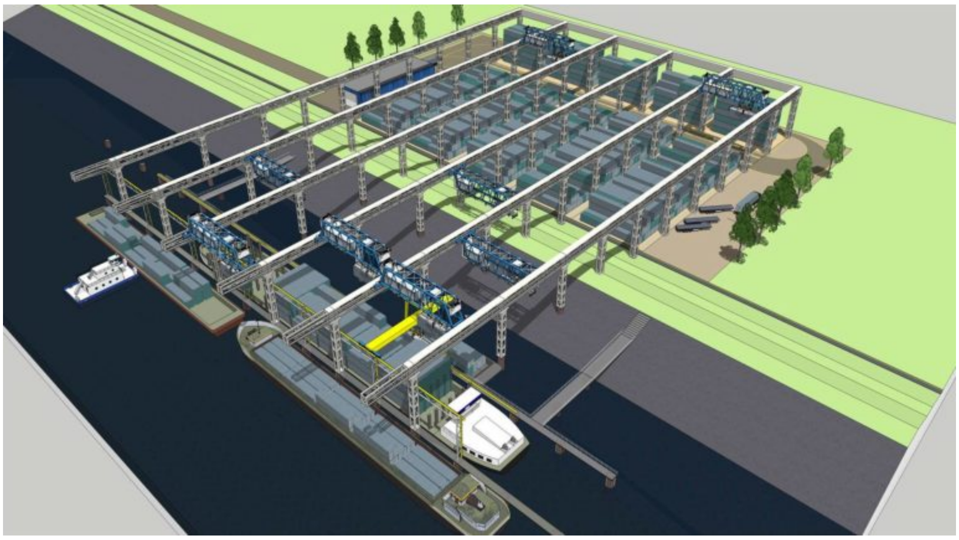
(a) Front view of passing OHCs.



(b) Side view of passing OHCs



(c) General overview from the side



(d) Top view of a multi-lane set-up

Figure 8.16: Overview of the main details for the NGICT Concept [Koch Adviesgroep, retrieved 02/07/2018]

Another advantage of the separated fixed quay crane could lie in the higher handling speed of the crane itself. With the crane's loss of one direction of travel, however, shortcomings arise. The NGICT itself cannot reach the entire hold. The vessel will therefore have to move during loading in order to present all of its hold slots to the crane. Having the vessel move is cumbersome, will lead to additional engine operating hours, and will demand active cooperation between the terminal and the captain of the vessel.

The vessel could be moved using "new" systems such as moving bollards and magnetic ship-to-quay fastening. Apart from this equipment being complex and new, and therefore expensive, the movement of the vessel will take time. This time reduces the effectiveness of the fixed crane. Moving a loaded SCCC over a distance of 12 meters (which is the distance to the next tier of containers) has to be done with care and therefore takes significant time. Locomotives (moving bollards) used at the Panama Canal are heavy-duty and can achieve a maximum speed of 1–2 meters per second [Panama Canal Authority, retrieved 02/08/2018]. It is to be expected that a low-cost inland application cannot achieve such high speeds. Additionally, accelerating and decelerating costs significant amounts of energy, negatively influencing the footprint of the terminal. Moving therefore takes a minute or more per bay slot.

Whereas the exact price for the concept parts is still unknown because no definitive order has been placed, estimates for the OHC and rails (resp. €500,000–€750,000 and €200,000 per 100 m of rail) were verified to be to low. The result is that even for a small-scale operation, an investment of, for example, €1 million per OHC and €0.4–€0.5 million for 100 m of support structure is required. When additional speed is required and a second OHC is ordered, another €1 million investment is required. The concepts illustrated in the figures sometimes even contain 3 OHCs, making the investment even greater. On the other hand, a small-scale terminal does not necessarily require such capacity. The scalability of such a solution is not possible, however, without significant investments.

The low-cost solution would be to use one OHC and one set of overhead rails and supports. This would be the smallest investment alternative, lowering the operating expenses. The result would be that the stack area could contain a maximum of four TEUs wide (2 times 40' or 45'). Stacking heights negatively influence the accessibility of containers, as was demonstrated in Chapter 5. At a height of four tiers, for instance, each line of containers can contain a maximum of 16 TEUs per 2.5 meters of stacking area or rail length. At €200,000 (which was to low), each 2.5 meters of rail would cost €5,000 per row. Compared to the RCC solution at a capacity of 384 TEUs, the OHC would require 24 rows, which would cost at least €120,000. The result is a significantly less expensive storage solution (the OHC is very costly). With €400,000–€500,000, the total cost would be €240,000–€300,000. This is, however, the bare minimum. If the average desired storage height was decreased to three tiers, the costs would increase by 25%. Lowering the stacking height to two boxes would double the storage costs.

The NGICT was found to be a superior handling concept in terms of speed and storage density. It is apparent, however, that for small-scale applications these points outweigh the expensive equipment and high cost of operation resulting from the limited use. Making the investment would mean spending money on specifications that would not be used.

8.5. Multi-Criteria Analysis of the Concepts

The four previously outlined concepts have many similarities and differences. Each have their own individual strong points compared to the competing concepts. A valid selection method is required to select the "best" concept overall. For this selection phase, in which most of the exact numbers from the concepts are relatively unknown, a precise monetary comparison cannot be made. As a result, the Multi-Criteria Analysis (MCA) was used as the weighing method. The advantages of the MCA approach lay in its ability to weigh criteria using different unit measures [Blauwens, 1986]. Additionally, weighing factors can place emphasis on more and less important criteria. Even removing unit measures and numbers completely by comparing the strengths and weaknesses with valuations ranging from zero to five, for example, is an option when performing an MCA.

This is, however, also the most common pitfall of this selection method. The results can be both intentionally and unintentionally steered towards a desired outcome. The selection then becomes more of a justification than a fair comparison. Overall, however, using widely accepted values and weighing factors can mitigate this danger of irrationality.

The help of experts was not used for this MCA, although that is often common practice. The literature analysis conducted in Chapter 5 was used to propose the weighing criteria. Since the concepts remain relatively vague, making sure the experts' interpretation of the concepts correspond to the desired application was the primary reason that expert opinions were excluded. Section 8.5.1 substantiates the scoring and appointed values.

Criteria and weighing factors for the concept evaluation are provided in Table 8.1. The first criterion is investment costs, which are important as a measure for the likelihood of adoption. If the required investment is very high, adoption is likely to be uncertain. The investment costs do not only influence startup; they remain fixed during the entire lifecycle, significantly affecting the operational cost via the CAPEX.

The second criterion is the everyday operational expenditure leading to a sustainable cost level. High operational costs lead to high tariffs and thus reduce the attractiveness of the terminal. The operational costs are in large part formed by labor costs. A concept that can operate with fewer personnel can therefore have lower costs. An automation investment that reduces the required workforce can be spread over a long period of time, while labor costs are a repetitive expense.

Handling capacity and speed of operations are of importance to the shipper and trucker at both ends. Chapter 3 indicated that the time cost of transport modes is a significant cost factor. If the concept terminal has low costs at an even lower handling rate, the result may be that time multiplied by the value of time will increase more than the handling costs are lowered. A potential time gain could be translated to a willingness to pay a higher handling charge, which is the sole source of revenue for the terminal.

Reliability is another important factor for operations. The more complex terminals are vulnerable to loss of operation. Similarly, a terminal that relies on a single piece of equipment for a crucial step in the handling process is vulnerable to loss of operation. Reducing this vulnerability can partially be accomplished by more R&M, leading to higher costs. The uncertainty is incorporated in the risk factor.

External costs are left out of the comparison since based on the proposed concepts in Sections 8.1 to 8.4, no viable estimation could be made. Roughly made assumptions would affect the scoring in a potentially unintended way.

Table 8.1: Overview of weighing criteria and weighing factors used for the selection of terminal concepts.

	Criterion	Associated cost factor		Weight
1.	Investment	Fixed Cost	→	35%
2.	Operational Expenses	Variable Cost	→	15%
3.	Handling capacity & Speed	Time Cost	→	40%
4.	Risk & Reliability	Uncertainty Cost	→	10%

Concepts are weighed using a valuation ranging from one to five. One means that one fifth of the criterion value is appointed, and five means that 100% of the criterion value has been accomplished. For Criteria 1 and 2 lower costs are better and are therefore valued highly with values of four and five. For Criterion 3, higher capacity and speed are preferred. The best expected operational speeds are awarded high values, while slower alternatives receive a one or a two.

Risk & reliability are slightly contradictory, because low risk and high reliability are desired. The impact of loss of operation is valued at one for a complete loss of operation, because restarting costs a lot of time and effort. Concepts that are influenced less by failing equipment are valued more highly. Reliability results from the number of people working (because they make mistakes) and the complexity of the equipment. The greater the reliability, the higher the assigned value is.

In addition to the primary criteria, a subdivision for secondary criteria is listed to ensure more accuracy. This second layer has split weights per subdivision. The sum of the secondary weights is equal to the primary weight factor. The weight allocation for the first two primary criteria and their secondary criteria is based on Smid et al. [2016] work (see Table J.2) and the analysis made in Chapter 5.

Table 8.2: Multi-Criteria Analysis of terminal concepts with equal weights per criteria.

	Weighing Criterion		Weight Factor		Concepts			
	Primary	Secondary	Primary	Secondary	RCC	CLC	XPC	FSSC
1.	Investment	Equipment		23	4	1	2	4
		Infrastructure	35	7	4	1	2	3
		Automation & ICT		5	5	1	2	4
2.	Opex	Labour		8	5	2	2	4
		Energy	15	5	5	3	2	5
		R&M		2	2	3	4	4
3.	Speed	Quay operations		18	4	3	3	4
		Storage	40	10	5	3	2	3
		Landside		12	4	4	4	3
4.	Risk	Loss of operation	10	4	2	3	3	3
	Reliability	Breakdowns & delays		6	3	3	4	4
5.	Total		100	100	82.0	46.8	52.4	74.4

Table 8.2 indicates the outcome when all four primary decisive criteria are valued. It reveals that the RCC and FSSC are valued first and a close second, while the XPC and CLC have scored significantly lower. The gap between the RCC and FSSC scores is 7.6 points. With the greatest secondary score at 23, a wrong valuation by one point could reduce this gap to 5.75 points. Errors at other points have lesser effects. As a result, it can be concluded that the result is reliable and independent of one or two changes in valuation. Shifts in the weight factors are even less impactful.

8.5.1. Justification of MCA Scores

Since no external experts were involved, a justification of the appointed MCA scores is provided below. Providing this justification ensures that only viable assumptions were made based on what is known until this point . The reader can compare his/her own impressions with those proposed in this subsection. In order to limit the amount of text and increase the readability, abbreviations are used (see the list of abbreviations on page xxi). The abbreviation of each concept can be found in the title of Sections 8.1 till 8.4.

1. Investment

Beginning with the first criterion, the RCC is expected to require a substantial but justifiable and scalable investment. The HCGC, quay conveyor, and at least 1 ETV and rack row are required to establish the terminal. When volumes increase, more equipment can easily be added. Automating the equipment will, however, demand a significant additional investment.

The CLC and XPC both require significantly higher investments. A minimum of carriages, moving equipment, and a straddle carrier are required, and the carriages and moving equipment are costly. Although the carriages are also loaded on board (similar to the XPC cartridges), the investment is linked to the terminal rather than the SCCC. For the XPC, the heavy lift crane is expected to be costly and must be built irrespective of the throughput volume. Scalability is difficult in this case. Additionally, automation is (very) difficult, and therefore very expensive, for both of these concepts.

Finally, the investments for the FSSC are equal to those required for a wide-span gantry crane. Although this is all “known” equipment, the prices are high even at a minimal startup size. The foundation for the cranes is, however, an important cost factor.

2. Operational Expenses
The automated RCC would incur minimal labor costs, low energy consumption, and moderate R&M. Operational expenditures are therefore estimated to be low. With the exposed conveyor belts and moving parts, R&M expenses are expected to be higher than those for alternative concepts. Energy usage is low because sliding transport is energy efficient and the superior accessibility eliminates the need for restacking.

The CLC would incur high to very high OPEXs. Automation is very difficult, leading to significant labor costs. The straddle carrier demands highly skilled, and therefore expensive, personnel. Hauling the carriages is heavy and delicate work, leading to high energy consumption.

A single operator can hoist the X-packs for the XPC concept, but the heavy lifting would require specialized staff and an additional workforce. Sorting and handling the containers in the pack could be done with workforce that would operate a reach stacker at a current terminal. As a result, the OPEX for XPC is estimated to be high. The double moves are also energy intensive.

Compared to the current terminal, the FSSC is estimated to have equal to (slightly) lower operational expenses. This proven concept works relatively well. The energy consumption will be lower with lighter, fixed crane parts.

3. Handling Capacity & Speed
The continuous operations made possible by the RCC lead to great speed. As a result, a valuation of four and five is awarded to the RCC. The HCGC is the bottleneck, but since it only has to move short distances, high speeds can be maintained.

The CLC allows for high speeds, but some of this operational speed is lost due to the ballast and trim limitations. The additional shore handling also leads to potential problems for direct transshipment to a truck. As a result, a three is awarded. Straddle carriers can, however, quickly conduct the landside operations.

The XPC would suffer similar bottlenecks and would also require additional shore handling. Not all containers are directly accessible after unloading, because they can be at the bottom of the X-pack stack. Because the X-packs are not used for storage at the terminal, more handlings are required.

The FSSC has acceptable performance but is dependent on the stacking area's length, width, and height. The higher the utilization rate becomes, the lower the speed will become because the number of handlings and distances will increase.

4. Risk & Reliability
Finally, the risk and reliability are compared. The RCC is valued lower than the other concepts because of the limited accessibility in the racks when the ETV breaks down. A normal crane or reach stacker cannot easily take over, increasing the effect/impact of loss of operation. The other concepts all have similar risk profiles. When the equipment fails, however, a temporary mobile crane can still take over the quay wall operations, because vertical lifting is still accessible for each individual box . Storage-wise, conventional equipment can take over when needed.

Reliability-wise, the RCC and CLC have more moving parts that are process-critical. These are, however, industry proof, but they form an Achilles' heel. The XPC and FSSC use (or are based on) existing equipment, leading to optimized designs and making them less prone to failures.

8.6. Intermediate Conclusions SCHC

MCA results showed the rolling conveyor concept as highest scorer. Its novel design, revolutionary approach to container handling and presumed superior characteristics led to the selection of this concept. From this point the concept receives more of its detailed engineering to work towards an overview consisting of costs and time/capacity specifications to incorporate into the feasibility study. The equipment is piecewise analysed and matched with its characteristics.

1. Hatch Coaming Gantry Crane
In cooperation with the SCCC vessels, the HCGC can exist in two widths, namely a 5-meter version (for the 2200/2300 series) and a 7.5-meter version (for the 3200/3300/3400 series). It is assumed that the 7.5-meter version is 25% more expensive than the 5-meter version. The costs are therefore also 25% apart. At €200,000 per half for the double-wide system, the combined costs are estimated at €400,000 and €500,000.

2. Coaming Rail

The hatch coaming rails are dependent on the hold length. Since both sides require a rail and additional coaming strength, these cost are calculated per meter, including both sides. The 7.5-meter version will bear more weight from the HCGC, increasing the additional coaming cost by 25%.

3. Quay Platform

The connection point of the vessel with the quay is a platform, as depicted in Figure 8.4a. This platform will have to receive 45-foot containers and will require a slider to reach out towards the vessel. Minimizing the quay-vessel gap and incorporating the gangway and width of the container (2.5 m), the platform should be able to reach out 4 to 5 meters. The platform consists of a simple fixed base with a sliding table on top. Costs are therefore assumed to be four times the slider table costs as defined below.

4. Scissor Lift

This piece of equipment should be capable of varying in height between just above ground level and the height of the quay platform (approximately 5 meters). It only performs vertical movement and requires some powered wheels to slide containers on and off. A robust lift is expected to cost €125,000. This is significantly less than the cost of the ETV because it is less complex.

5. Slider Table

The slider table is comparable to a standard piece of conveyor but with an additional set of wheels at a perpendicular orientation. The sliding tables are expected to cost around €75,000 each.

6. Rolling Conveyor

As previously mentioned, no belt or small cylinder conveyor can or should be used. High local loads will mean that more wear and tear will occur, which will lead to higher R&M and/or more frequent failure. Axes with heavy-duty wheels (for example, forklift truck wheels or old car tires) every couple of meters should be sufficient for moving the containers. These wheels will have little wear and tear, because every container that passes compares to only 12.5 meters of travel, which is marginal compared to a regular wheel's lifetime. The rolling conveyor is estimated to cost €300,000 per hundred meters. This is the result of a calculations with axes every 2 meters at an estimated cost of €6,000 per axis including the support structure.

7. Elevating Transfer Vehicle

A similar yet more complex version of this equipment piece is used in the (un)loading of airfreight. The Trepel Champ 350 is the most heavy-duty version currently on sale at an approximate price of €500,000 (a price of $580,000 was found at Moscow Cargo [retrieved 02/08/2018] and converted to euros according to the 02/08/18 conversion rate of €0.86/$1). Transferring this to a more simplistic, rail mounted, externally powered ETV, the costs are expected to lower towards €300,000.

8. Elevating Transfer Vehicle Rail and Support

The combined weight of the ETV and a loaded container is estimated to be 50 tonnes. This means that the tracks over which the ETV moves require significant support. The cost of these rails is estimated to be €250,000 per hectometer.

9. Rack

In Chapter 4, the new price of a container was found to be approximately €3,000 per 40-foot HC container. If the support and storage racks are assumed to contain twice the amount of steel and require some foundation work, a rough estimate of €10,000 per storage location is proposed. The terminal illustrated in Figure 8.9, which has three layers, 16 rows, and four racks would therefore cost €1.92 million.

The cost of this rack system is the most critical portion of the overall terminal cost structure. In the case of 192 bays, reducing the cost per bay by €1,000 results in an immediate saving of almost €200,000. Costs per bay are deemed irrespective of the stacking height. The top layer may require less steel, making it less costly; however, the result is that the bays below will require additional strength (material), and the foundation will need to be stronger.

10. Rack Sled
A simple support sled is proposed to roll the containers over the conveyor. These sleds are simpler than the bottom of a standard container and are therefore assumed to cost €1,000 each.

11. Landside Portal Crane
An overhead crane with a minimal support structure should not cost more than €200,000. Since the terminal could be operated unmanned, the costs are assumed to be €100,000 for an overhead crane, €50,000 for the support structure, and €50,000 for automation.

The resulting costs are displayed in Tables 8.3 and 8.4. Table 8.3 lists the costs that are ship bounded , while Table 8.4 lists the terminal bound costs.

Table 8.3: Cost of equipment for the SCHC concept

	Piece of equipment	Cost 5m version	Cost 7.5m version	Unit
1.	HCGC	€ 400.000	€ 500.000	Per piece
2.	Coaming rail	€ 2400	€ 3000	Per metre of coaming

Table 8.4: Cost of equipment for the SCHC concept

	Piece of equipment	Cost	Unit
3.	Quay platform	€ 300.000	Per piece
4.	Scissor lift	€ 125.000	Per piece
5.	Slider table	€ 75.000	Per piece
6.	Conveyor	€ 300.000	Per 100 meter
7.	ETV	€ 300.000	Per piece
8.	ETV rail	€ 300.000	Per 100 meter
9.	Rack	€ 10.000	Per bay slot
10.	Box sled	€ 1.000	Per piece
11.	Landside portal crane	€ 200.000	Per piece

Using the example illustrated in Figure 8.9, the shore base equipment is estimated to cost nearly €4.6 million, and the total sum is just over €5.3 million. Table 8.5 shows the calculation .

These are solely equipment costs. Chapter 5 and Appendix J outline the other cost factors such as labor, fuel, interest, and land cost, which also play a significant role. Whereas the equipment costs for the RCC terminal are higher than those at current terminals using wide-span gantry cranes, labor can be all but neglected, and some overhead and fuel costs will be lower.

The costs of ICT will be higher for a totally autonomous and unmanned terminal that is fully electric. Since the investment in ICT is mitigated over a long period, however, the impact is marginal.

Table 8.5: Cost of equipment for the RCC example terminal concept

	Piece of equipment	Amount	Unit cost	Total cost	Technical lifetime	Annual R&M
3.	Quay platform	1	€ 300,000	€ 300,000	25 years	5%
4.	Scissor lift	2	€ 125,000	€ 250,000	15 years	8%
5.	Slider table	6	€ 75,000	€ 450,000	15 years	5%
6.	Conveyor	≈ 120m	€ 300,000	€ 360,000	10 years	8%
7.	ETV	2	€ 300,000	€ 600,000	15 years	5%
8.	ETV rail	≈ 2x50m	€ 300,000	€ 300,000	25 years	2%
9.	Rack	192	€ 10,000	€ 1,920.000	25 years	2%
10.	Box sled	192	€ 1,000	€ 192,000	10 years	2%
11.	Landside portal crane	2	€ 200,000	€ 400,000	25 years	5%
Total Equipment Cost				€ 4,772,000		

A dwell time analysis and corresponding capacity requirement for the concept terminal is the subject of Section 9.4. Including the results from that analysis, the sample terminal with its 192 slots is equipped to handle an annual throughput of over 40,000 TEUs.

Table 8.6 lists the total annual cost of operating the RCC terminal for the first year. Given the assumption that the terminal investment should be repaid in 10 years and the terminal is built at full capacity, capital expenses are fairly high from the beginning. When 24,000 boxes (40,000 TEUs) are passing over the explanatory terminal, the cost per box would be €53.50 (rounded). Comparing this with the current market costs determined in Chapter 5 reveals that a very competitive cost level is achieved. This concept is therefore promising.

The example RCC terminal serves as an indicator of what size of terminal could be operated on a piece of land that is approximately 1 hectare at what cost. The resulting 384 or 512-TEU capacity is the resulting value. Whether or not this amount of storage is required has not been discussed. The need for storage is a result of the throughput volume and the dwell time. Both of these could be considered cost-dependent. Under the assumption of a fixed TEU supply and demand within the potential service region of the future terminal, price and service will decide the share of containers using the terminal and the SCCC transport solution. Lower costs will automatically increase the throughput share and thereby the volume of containers passing through the terminal.

Additionally, dwell time is dependent on the sailing frequency and cost of storing a container at the terminal. If the sailing frequency is low (once per week), the container could require storage for as long as six days after being transported to the terminal. Dwell time forecasts have been made in Section 9.4. If the cost for storing is higher than the difference between IWT and truck haulage, it is likely that the client will prefer the haulage solution. At higher sailing frequencies, dwell time could be partly determined by increasing the storage cost. This costly storage then negatively influences the service of the terminal, reducing the overall attractiveness and GC of the transport solution.

Table 8.6: Cost of operating the RCC example terminal

Cost factor	Unit	Cost
Investment		
Area	1 ha	€ 750,000
Quay	100 m	€ 100,000
Fence & lighting	1 ha	€ 75,000
Equipment	-	€ 4,772,000
Subtotal		€ 5,697,000
Fixed Cost		
Interest	6%	€ 341,820
Principle	10 years	€ 379,800
CAPEX		€ 721,620
Variable Cost		
Electricity	€/year	€ 100,000
ICT	€/year	€ 150,000
Overhead	€/year	€ 50,000
Misc.	€/year	€ 25,000
Subtotal		€ 325,000
R&M		
Area	1 ha	€ 10,000
Quay	100 m	€ 25,000
Equipment	€/year	€ 184,540
Fence		€ 3,000
Misc.		€ 15,000
Subtotal		€ 237,540
OPEX		€ 562,540
Total Annual Cost		1,284,160

IV

Feasibility Study

Part IV

Inland Waterway Transport in Europe:
No significant improvements in modal share and navigability conditions since 2001
-
European Court of Auditors, 2015

9
Individual Part Performance Analysis

The previous part presented the design of the scalable container carrier concept and the scalable container handling concept. These concepts have great promise, but their feasibility has yet to be assessed. The following part therefore performs a feasibility study.

No dedicated transport voyage is under review, which means that no fixed origin and destination is the subject of research. Hence, the focus is not placed on one case. Using a scenario approach will research the adoption of the concepts under variable conditions. The results of the feasibility check will indicate if and for what conditions the concepts will provide the most preferable transport alternative.

The literature review in Part II provided insight on several important variables such as a.o. sailing distance, handling cost, PPH distance, frequency, annual volume, and the internalised external cost. A set of figures that are like those in figure 5.9b could be produced to determine the interdependence of the main part IWT distance, handling cost, and the resulting PPH distance.

The feasibility study will consist of analysing the concepts' performance in a set of scenarios. The model used for these assessments enables custom research for a desired condition. Results will indicate a best or most preferred solution even if the assessment of feasibility is negative. A sensitivity analysis then clarifies the underlying reasons.

Section 9.1 starts with an explanation regarding the scenario's of interest. Since pre- and post-haulage are assumed to be carried out by an external party these costs are fixed. The costs of PPH are discussed in section 9.2. General remarks are discussed in Section 9.3. Performance of the concept terminal is analysed in section 9.4. Section 9.5 contains the analysis regarding concept vessel performance.

The objective of the individual performance analysis is to gain insight and understanding of all concept parts. The knowledge should make it easier for an interesting case to present itself. Section 10 will conclude what direction chapter 10 should examine.

9.1. Variables of Interest

Variables of interest include individual performance of interest. The primary reason of interest is the individual performance, apart from clouding due to secondary effects. If the terminal's individual sensitivity to changing conditions is of interest, any influence from the SCCC call size or resulting frequencies could lead to a different result from what was sought.

One of the variables relates to the pre- and post-haulage distance and costs. It was earlier assumed that this service is provided by an external party because road haulage is a different business from inland shipping. Since the CEMT Va barge cannot penetrate the capillaries of the inland waterway network, larger PPH distances are required. Chapter 6 demonstrated that these distances were selected at 50-200 km. For the SCCC and SCHC, tandem penetration of the network with the small waterways means that the terminal can be situated closer to the destination. The result indicates that less remaining distance must be covered by PPH. At smaller distances, the waiting times and call-out costs might have a more considerable effect.

Chapter 8 discussed the proposal of the rolling conveyor concept (RCC), but the concept's precise performance is not known. One of the variables of interest is scalability's effects on the costs. Section 9.4 discusses the effect that increased frequency has on the required capacity, growth potential, and costs. This effect can be compared to varying SCCC conditions. This is turn will indicate the preferred combination.

Chapter 7 developed the SCCC, which seeks to provide the best-suiting inland container vessel under all conditions. This concept provokes questions regarding the effect of economies of scale (EoS), loading degrees, sailing speeds, and sailed regimens. These questions are the subject of section 9.5. Analysing these variables will indicate the impact of changes and which set of variables should be preferred. Matching them with the SCHC will reveal which case is the most promising for further research.

9.2. PPH Performance

Similar to the approach of chapter 6, PPH will be required. This activity is deemed to be fully outsourced, which means that no vertical integration is in action. The main argument for this assumption is that the truck haulage business significantly differs from the inland waterway transport market that this research focuses on. As a result, the incurred PPH costs are deemed to be fixed, and neither a loss nor profit will be made on this expense.

The realistic PPH range for the SCCC concept ranges from 20km to 80km. Pre- and post-haulage in tandem with the SCCC and SCHC also use the generalised cost approach. Since chapter 6 already discussed the calculation methods and approach, this section will only provide the resulting values. Table 9.1 presents the generalised cost breakdown. It is assumed that R&R is mitigated because insignificant detours can be made in a local setting when congestion or delays are to be expected. Furthermore, since the distribution is local, frequent bottlenecks are known and rush hour can be pre-empted.

Results indicate that 80km PPH is twice as expensive as 20 km PPH, while the distance is four times as high. This is caused by the call-out costs and waiting time at the SCHC and clients that are the same, irrespective of the distance.

Table 9.1: Break-down of the generalised cost of PPH when operated in cooperation with the SCCC and SCHC.

Distance	20km	30km	40km	50km	60km	70km	80km
OOP	€132.33	€151.68	€171.03	€203.75	€223.10	€242.45	€275.18
Time	€9.80	€9.80	€9.80	€9.80	€9.80	€9.80	€9.80
R&R	€ -	€ -	€ -	€ -	€ -	€ -	€ -
EC	€97.37	€146.06	€194.74	€243.43	€277.60	€311.77	€345.94
GC (excl.)	€142.13	€161.48	€180.83	€213.55	€232.90	€252.25	€284.98
GC (incl.)	€239.50	€307.53	€375.57	€456.98	€510.50	€564.02	€630.91

9.3. General Results Remarks

To prevent a repetition of results and corresponding causes several general remarks are made. These remarks are effective over all results and apply to the use of the SCCC. The SCCC is selected because no dedicated container concept is currently present for CEMT ≤ IV.

9.3.1. Sailing Frequency and Distance Effect

Sailing frequency of interest is either once or twice per week. With the IWT's navigating speed and the time taken at the terminals, and sailing distance: more than two sailings per week are impossible for distances of interest.

The effect of the sailing frequency trickles down to many aspects. At a certain annual transport volume, ship capacity can halve if the frequency is upgraded to two calls per week instead of one. The primary effect of increasing the operations is that many costs that would have to be incurred by one trip will be incurred by two operations per week. The relative pressure of these cost factors thus decreases significantly. For example, insurance, overhead, and capital costs are effectively halved when a ship doubles its activity. However, a smaller ship will lose its EoS due to increased labour costs, R&M , and fuel cost per TEU.

Figure 9.1 does indicate the correlation between the ship's average speed and the roundtrip duration for distances that range between 50 km and 1000 km. Figure 9.1c demonstrates that for A1, roundtrip duration is 1 week at distances ≤ 200km for all speeds, 250 km at speeds ≥ 15 km/h, and 300 km at speeds ≥ 17.5 km/h. [1] If the distance becomes greater, the vessel will not be able to make a roundtrip in 5 days of 14 hours each (70 hours in total) if loading at both ends is included. The result is a delay over the weekend, during which no navigation can take place. Sailing is immediately resumed the day after.

It is important to note that A1 represents a sailing regimen in which 5 days of 14 hours each can be used for operations per week. The other two days are a mandatory resting period. A2 allows for 18 hours per day as additional staff is onboard. B uses a double crew which allows for operations around the clock [Van Kester, 2014a].

When the distance increases beyond 650km, a second weekend must be considered. Hence, depending on the distance and speed, A1 roundtrips can take between 1 and 3 weeks. Increased working hours in the form of A2 increase the sailing hours, thereby shortening the roundtrip times Figure 9.1b illustrates that more distances fall within the 1-week range, and the remaining distances can almost all be sailed within a 2-week period. Only six out of a total of 220 data points cannot make a roundtrip within two weeks. When sailing scheme B is used, almost all cases fall within the 1-week roundtrip window. In reality, a shipowner will never sail at the very low speeds when navigating with scheme B. For very large distances unless there is a good reason to do so.

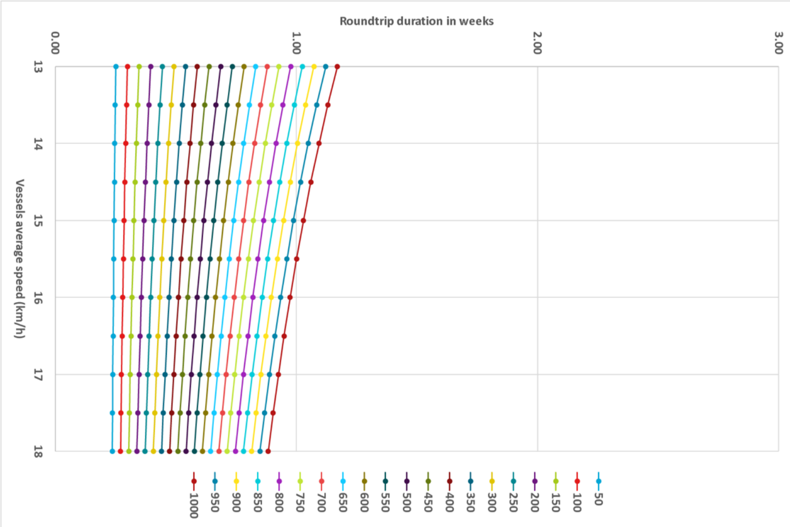
Applying this analysis to the SCCC yields the following conclusions. The SCCC cannot offer a weekly call to the SCHC terminal in case the roundtrip time is longer than one week. This would require the purchase of a second SCCC. Three SCCCs are required in case the roundtrip takes three weeks.

In case the sailing distance only leads to a 2-week roundtrip it is advised to increase the speed or the sailing regimen to prevent the purchase of an additional vessel. Frequent calls at the SCHC terminal (such as on each Wednesday) require a ship to be sailing each week. If the roundtrip of 350 km at 15 km/h is taken as an example under A1, this trip will take 1.13 weeks (8 days) and will then most likely remain idle for 6 days before a new roundtrip can be started. Maximizing the speed to 18km/h will have no effective result other than additional fuel costs.

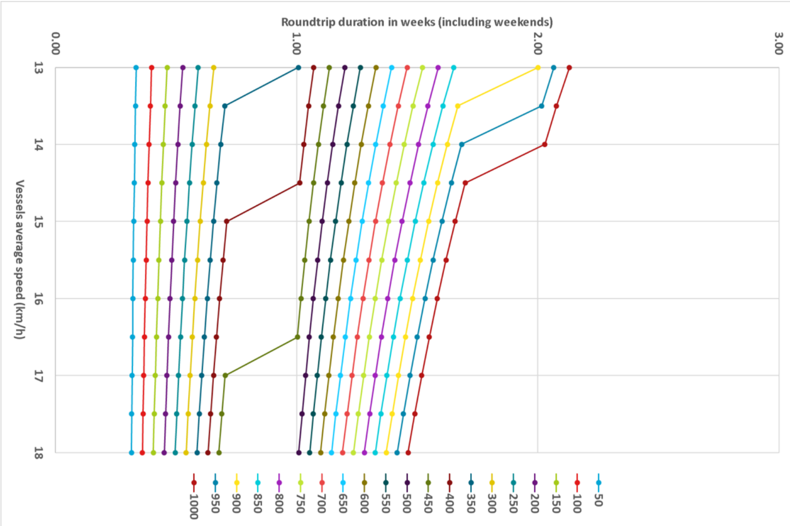
Adopting regimen A2 will decrease the roundtrip duration to less than a week (5 days). The speed can even be lowered to 14 km/h for the same roundtrip duration, which will reduce fuel costs and lower the overall transport cost. However, the most beneficial result is the ability to perform 50 calls per annum and thereby remove the need for a second SCCC.

Changing the regimen to B and increasing the operational speed can lower the roundtrip duration below 3.5 days. This would double the frequency to two calls per week without the need for an additional vessel. In that case, the SCCC is optimally used in terms of useful days, which reduces the fixed cost to the lowest attainable level.

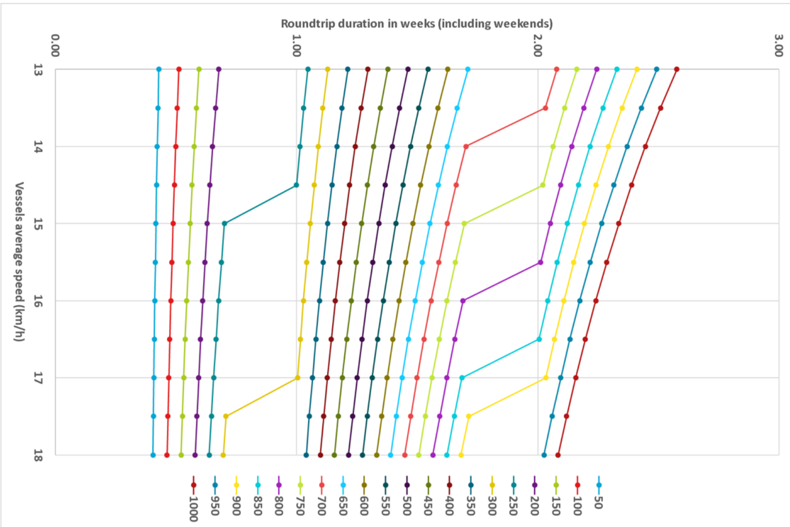
[1] The average speed of for instance 17.5km/h represents a speed through the water of 17.5km/h. Due to currents the effective speed over the ground (SOG) is 14.5km/h upstream and 20.5km/h downstream.



(a) Speed vs Distance for sailing regime B



(b) Speed vs Distance for sailing regime A2



(c) Speed vs Distance for sailing regime A1

Figure 9.1: The duration of a round trip depending on the distance and average speed

9.3.2. Sailing Distance Effect

Like the frequency, the distance also poses limitations. Handling at the ARA and IT ports varies with the call size, but assume the time taken to be 32 hours in total. Applying navigation schemes A1/A2/B with 70/90/168 operation hours each, means that 38/58/136 sailing hours are left after handling time is subtracted. Table 9.2 indicates the distance that a vessel can cover under different average operational speeds and demonstrates that A1 and A2 are useful for distances up to 340 and 520 kilometres. Using scheme B rapidly increases the navigating range. However, these ranges are only applicable for unhindered navigation. Locks and bridges will lower the effective speed, thereby limiting the range.

Table 9.2: Sailing range depending on average sailing speed and operational profile. (Under the assumption of 32 hours handling time per roundtrip)

		Sailing Scheme / Regimen		
		A1 = 14/5	A2 = 18/5	B = 24/7
Sailing hours left		38	58	136
Average sailing speed (km/h)	12	228	348	816
	13	247	377	884
	14	266	406	952
	15	285	435	1020
	16	304	464	1088
	17	323	493	1156
	18	342	522	1224

9.3.3. Financing Considerations

The focuses of the SCCC and SCHC are the cost of operation at small annual volumes. A significant portion of the cost is associated with capital expenses. The required investment must be financed, which will partly come with external sources such as bank loans. The required amount, type of financing, running period, and interest rate will all affect the annual required payment. This Subsection provides insight on the different variables and assumptions.

The most common types of loans are annuity and linear loans. When these were introduced, Subsection 3.1.2, the annuity type had been selected for ease of computation. In inland shipping, it is currently more common to acquire a linear repayment loan [Mercurius schipping group, 2018]. The primary investor is usually a bank and is willing to finance up to 50-60% of the total investment. This automatically means that the shipowner must find 40-50% of the remaining loan to pay for the vessel and start its business. This money will likely be out-of-pocket or financial support from relatives.

The running period of a bank loan for a newly-built inland vessel is 20 years at most. This means that for a linear repayment schedule, the owner will have to repay 5% of the investment per year. Due to the limited risks, banks are currently prepared to take the final repayment after 10 years [Mercurius schipping group, 2018]. This requires a large amount of cash or refinancing of the remaining loan under a new contract. With the linear repayment schedule, interest payments during the first 10 years have been very high, which almost certainly results in the need for refinancing. Table 9.3 provides an example of capital cash flow for an investment of €2.5 million that is linearly repaid in 10 years.

The three different interest rates are worth examining. At 4% of interest, the first payment is €100,000 of interest and €125,000 of the principal, the actual amount repaid. This is almost similar to the interest payment alone if the rate were 8%. At the end of year 10, the principal payment is the remaining loan of €1,375,000. This is substantial payment on its own. However, the difference in interest paid in 10 years between low and high interest is €775,000. In that case, money would be saved by having a low rate of interest, and these savings could be used to repay more than half of the remainder.

Table 9.4 depicts an annuity repayment cash flow that is compared to the linear scheme. The annuity payment is equal to the annual payment of the linear 6% case of €275,000 per annum. The results clearly indicate that the annuity enables significant repayment in case of low interest. In case the interest rate is 4%, the remainder after 10 years is €400,000, which is almost €1 million lower than for the linear repayment. However, at a high interest rate, the repayment is slow, and the remainder is higher.

The linear loan has annual repayments that are highly dependent on the interest rate. This is especially true during the first years when the remainder is still high, and a high outgoing cash flow is therefore required. Insufficient revenue generation during the start-up of the business could quickly lead to cash flow problems and potential default. However, this option enables the security of the knowledge that a fixed amount has been repaid after 10 years and of the amount of the remainder.
Overall it is shown that the linear loan has annual repayments highly dependent on the interest rate. Especially during the first years in which the remainder is still high a high outgoing cash flow is required. Insufficient revenue generation during the start-up of the business could quickly lead to cash flow problems and potential default. At the same it is however also known that a fixed amount has been repaid after 10 years and what does still remain.

Using an annuity spreads the annual cash flow over a longer period. However, this comes at the cost of delayed risk because repayment is very slow, especially for higher interest repayment because the majority share is spent on interest payments.

This analysis has not mentioned methods of financing the remaining 40% because this is too complex at this stage. Mezzanine loans, angel investors, and Islamic funds are examples of specialised financing alternatives that have been left out of this analysis.

Table 9.3: Linear repayment example of a €2,5 million investment at a starting payment of €275,000.

Running year	Remainder	Interest payment (4%)	Interest payment (6%)	Interest payment (8%)	Principle payment
0	€ 2,500,000	€ -	€ -	€ -	€ -
1	€ 2,375,000	€ 100,000	€ 150,000	€ 200,000	€ 125,000
2	€ 2,250,000	€ 95,000	€ 142,500	€ 190,000	€ 125,000
3	€ 2,125,000	€ 90,000	€ 135,000	€ 180,000	€ 125,000
4	€ 2,000,000	€ 85,000	€ 127,500	€ 170,000	€ 125,000
5	€ 1,875,000	€ 80,000	€ 120,000	€ 160,000	€ 125,000
6	€ 1,750,000	€ 75,000	€ 112,500	€ 150,000	€ 125,000
7	€ 1,625,000	€ 70,000	€ 105,000	€ 140,000	€ 125,000
8	€ 1,500,000	€ 65,000	€ 97,500	€ 130,000	€ 125,000
9	€ 1,375,000	€ 60,000	€ 90,000	€ 120,000	€ 125,000
10	€ -	€ 55,000	€ 82,500	€ 110,000	€ 1,375,000
Total paid (sum) after 10 year		€ 775,000	€ 1,162,500	€ 1,550,000	€ 2,500,000

Table 9.4: Annuity repayment example of a €2.5 million investment at annual interest + principle payment capped at €275,000.

Running	Remainder			Interest payment			Principle payment		
year	4%	6%	8%	4%	6%	8%	4%	6%	8%
0	€ 2,500,000	€ 2,500,000	€ 2,500,000	€ -	€ -	€ -	€ -	€ -	€ -
1	€2,325,000	€ 2,375,000	€ 2,425,000	€ 100,000	€ 150,000	€ 200,000	€ 175,000	€ 125,000	€ 75,000
2	€ 2,143,000	€ 2,242,500	€ 2,344,000	€ 93,000	€ 142,500	€ 194,000	€ 182,000	€ 132,500	€ 81,000
3	€ 1,953,720	€ 2,102,050	€ 2,256,520	€ 85,720	€ 134,550	€ 187,520	€ 189,280	€ 140,450	€ 87,480
4	€ 1,756,869	€ 1,953,173	€ 2,162,042	€ 78,149	€ 126,123	€ 180,522	€ 196,851	€ 148,877	€ 94,478
5	€ 1,552,144	€ 1,795,363	€ 2,060,005	€ 70,275	€ 117,190	€ 172,963	€ 204,725	€ 157,810	€ 102,037
6	€ 1,339,229	€ 1,628,085	€ 1,949,805	€ 62,086	€ 107,722	€ 164,800	€ 212,914	€ 167,278	€ 110,200
7	€ 1,117,798	€ 1,450,770	€ 1,830,790	€ 53,569	€ 97,685	€ 155,984	€ 221,431	€ 177,315	€ 119,016
8	€ 887,510	€ 1,262,817	€ 1,702,253	€ 44,712	€ 87,046	€ 146,463	€ 230,288	€ 187,954	€ 128,537
9	€ 648,011	€ 1,063,586	€ 1,563,433	€ 35,500	€ 75,769	€ 136,180	€ 239,500	€ 199,231	€ 138,820
10	€ 398,931	€ 852,401	€ 1,413,508	€ 25,920	€ 63,815	€ 125,075	€ 249,080	€ 211,185	€ 149,925
Total paid (sum) after 10 year				€648,931	€1,102,401	€1,663,508	€2,101,069	€1,647,599	€1,086,492

9.4. SCHC: Cost of Operation

Chapter 8's analysis led to the design of a preferred scalable container handling concept in the form of rolling conveyors. The primary advantage of the scalable handling concept is its ease of adoption and alteration when the cargo volumes increase. A separate SCHC result section, 9.5, is used to limit the degrees of freedom for the entire scalable concept chain. This prevents the terminal and inland vessels from adversely affecting each other in the results and analysis phase.

9.4.1. Throughput of Containers

This Subsection begins with an analysis of the cargo flow or throughput of containers. The focus is on small vessels and small terminals, which leads to limited cargo volumes per annum. Table 5.3 demonstrated the interdependency of annual throughput, call size, and frequency of calls. To limit the variance in options, small flows are from now on calculated as ≤ 20,000 TEU (12,000 boxes) per annum. Since frequency is important [Konings, 2009], a minimum service frequency of once per week is adopted. Due to the upper limit, it is argued that daily sailing would provide the most attractive business alternative. However, because EoS affect the costs more than an additional day, the realistic maximum frequency is two calls per week. The number of operational weeks per annum was predetermined and set to 50. This results in the volumes (call size, which is inbound plus outbound) that are depicted in Table 9.5.

Table 9.5: Example of resulting annual throughput volume in TEU depending on the call size times the sailing frequency. Volumes assume 50% inbound and 50% outbound shares.

Annual Throughput		Weekly Volume		Call size 1/week		Call size 2/week		Call size 3/week		Call size 7/week	
Boxes	TEU	Boxes	TEU	Boxes	TEU	Boxes	TEU	Boxes	TEU	Boxes	TEU
1500	2500	30	50	30	50	15	25	10	17	4	7
3000	5000	60	100	60	100	30	50	20	33	9	14
4500	7500	90	150	90	150	45	75	30	50	13	21
6000	10000	120	200	120	200	60	100	40	67	17	29
7500	12500	150	250	150	250	75	125	50	83	21	36
9000	15000	180	300	180	300	90	150	60	100	26	43
10500	17500	210	350	210	350	105	175	70	117	30	50
12000	20000	240	400	240	400	120	200	80	133	34	57

The assumed dwell time follows the trend of equation 9.1. The call size (a) is multiplied by the pick-up rate (b), which incorporates the time from the previous call. Decent estimates were found for $b = 0.4$ when the call frequency equals once per week and $b = 0.5$ at two calls per week. Three calls per week uses $b = 0.6$ and seven calls per week uses $b = 0.8$. The average required storage capacity for these two cases is depicted in figure 9.2. For one call per week, the capacity requirement ranges between almost none to very high, while upgrading to two calls per week evens out this effect. The terminal will have a different capacity depending on the service frequency and call size. It is at the same time shown that in case the operated frequency increases for a given call size, a second call is added, the required terminal capacity does not double. Twenty-five percent excess capacity is incorporated to enable realistic operations. In reality, a container ship will not directly replace an unloaded box with a new container. This would mean that only the top tier is available for (un)loading.

When the terminal is first operated at 3,000 boxes (5,000 TEU) and one call per week, the required capacity is minimally 38 boxes. Doubling the operation to 6,000 boxes would increase the required capacity to 77 boxes at one call per week. If the call size is increased to twice per week, the required capacity increases to 45 boxes. The result is that the capacity does not require doubling, but a capacity increase of 20% will suffice. From the viewpoint of the terminal, increasing the frequency should be preferred over increasing the call size.

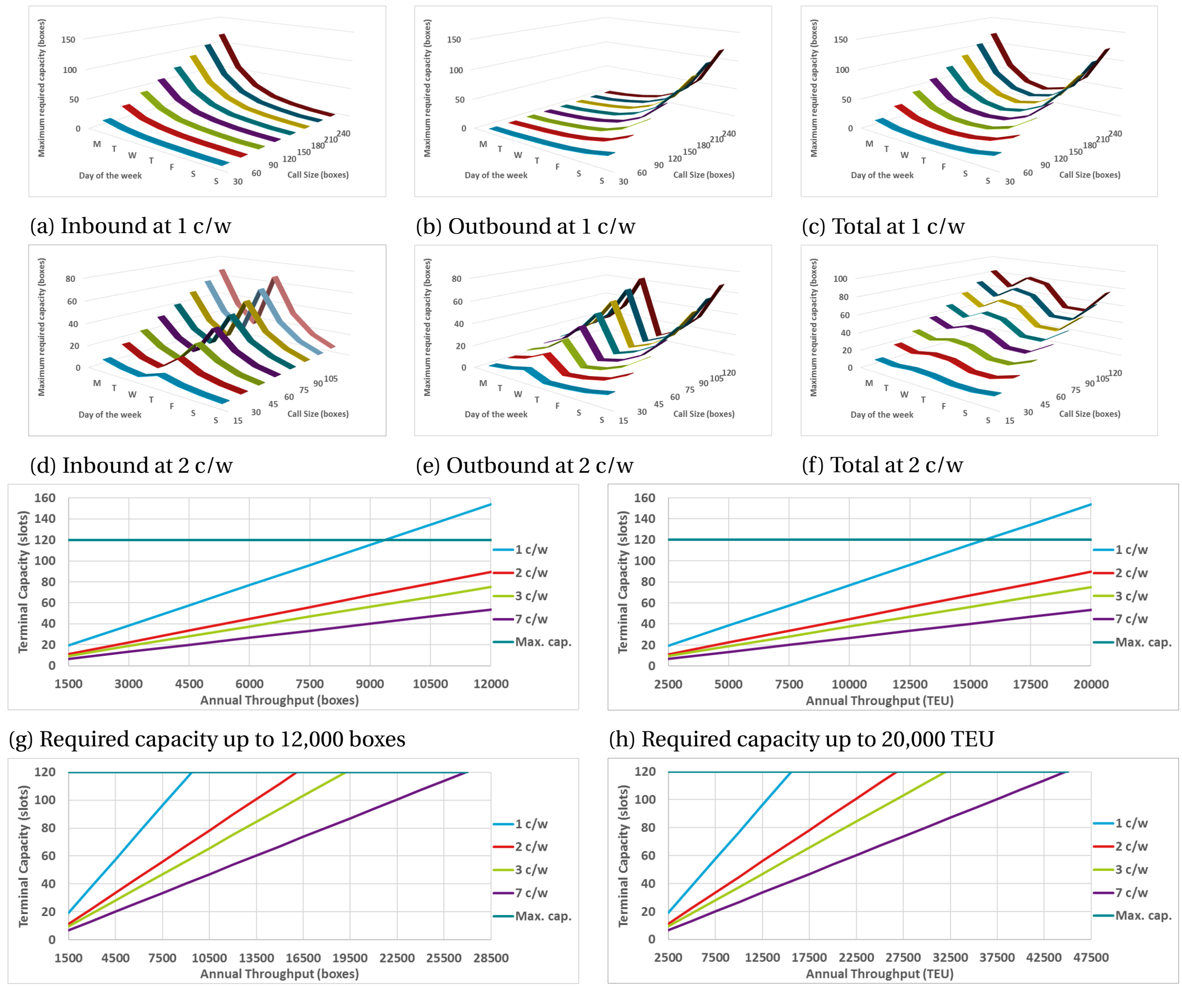
$$\text{Remaining stack} = a \cdot b^t \tag{9.1}$$

This knowledge can be applied to the required terminal capacity of the rolling conveyor concept (RCC). Chapter 5 explicitly mentioned the necessity of growth for small terminals to reduce their operating costs. There is no difference for the SCHC. It would thus be unlikely that the terminal would start at a location with no opportunity for growth.

The largest SCCC (*'3413'*) can transport 156 TEU at full capacity, which allows for a maximum call size of 312 TEU per week or 15,600 per year. Figure 9.2h indicates that for 15,000 TEU and one call per week, the minimum required capacity is 115 boxes; for 17,500 TEU, the minimum capacity is 135 boxes. Interpolating and rounding up the answer leads to a minimum required capacity of 122 boxes if the terminal is operating at maximum efficiency and no long stored containers are present. This amount includes the additional 25% space. The choice has therefore been made to set the required capacity for this case at 120 boxes; the reasons will be elaborated on later.

The small terminal (≤ 20,000 TEU/annum) at two calls requires even less capacity, as can be seen in Figure 9.2g. At 120 boxes and two calls per week, the annual capacity of the terminal becomes ≈ 26,800 TEU/annum. This would leave plenty of growth potential for the terminal. Figures 9.2i and 9.2j demonstrates that the terminal throughput capacity would become 19,200 boxes (30,000 TEU) at three calls per week. In the extreme case of daily calls, the terminal can even grow to 26,880 boxes (44,800 TEU) without the need for additional investments because the 120-slot terminal is sufficient.

The distance between the lines of Figures 9.2g till 9.2j indicate that increasing the call frequency from one to two calls per week has a major impact: the effective call size per call is halved. Between two calls and three calls per week, this effect is far less strong because the call size decreases from 50% to 33%. The terminal's efficiency is maximized at seven calls of one-seventh of the call size. On average, the number of containers is spread over all days of the week, which eliminates peaks and troughs.



(a) Inbound at 1 c/w
(b) Outbound at 1 c/w
(c) Total at 1 c/w
(d) Inbound at 2 c/w
(e) Outbound at 2 c/w
(f) Total at 2 c/w
(g) Required capacity up to 12,000 boxes
(h) Required capacity up to 20,000 TEU
(i) Attainable capacity (boxes) at 120 slots capacity
(j) Attainable capacity (TEU) at 120 slots capacity

Figure 9.2: Capacity requirement. Sub figures a till c are for one call per week and d till f for two calls per week.

The following assumptions must be made for an analysis of the required terminal dimensions. The required capacity for one call per week is 120 box slots or rack slots. At two calls per week, the efficiency grows, decreasing the required space. The expected annual throughput of a small terminal is capped at 20,000 TEU. This translates to 12,000 boxes via the default TEU:FEU ratio of 1:2. When the terminal grows to dimensions above that level, the small-scale scope is lost.

The SCHC can store one box per side per layer of an alley. For two alleys that stack three boxes high, the capacity is 12 boxes per 3 m of alley length. For a minimum of 120 slots of storage, 10 rows would be needed to create a depth of 30 metres. Together with the quay and land side depth, [2], the terminal will require 70 metres of depth, which means that the area will use 0.70 hectares ($100m \cdot 70m$). The available capacity is the result of the following calculation.

$$\text{Capacity} = \text{Length of alley} \cdot \text{number of alleys} \cdot \text{rack stacking height} \tag{9.2}$$

If the rack system only uses two-layer stacking, the capacity per row per alley drops from 12 boxes to 8 boxes. If the number of rows is increased to 15 with two alleys, the alley length becomes 45 metres. Alternatively, the required terminal size can be increased to 0.85 hectares ($100m \cdot 85m$). Both cases will be run to find the lowest cost alternative.

The first terminal design focusses on three-layer (3L) stacking. At least one alley of 30 m rail length is required to connect the quay with the land side transfer zone. This would create capacity for 20 boxes with one layer. Each rack layer will add another 20 boxes of capacity. In addition, another alley will also add 20 boxes of capacity per layer.

Table 9.6 demonstrates the cost per unit. The start terminal allows up to 20 boxes of storage at the investment of ≈ €1.55 million. This is sufficient for annual handling of 2600 TEU at one call per week or 4,470 TEU at two calls per week.

Table 9.6: Cost of equipment for the SCHC concept

Piece of equipment	Cost per unit	Unit	Start layout	Additional Layer	Additional Alley	Full capacity
Quay platform	€ 300,000	per piece	1	0	0	1
Scissor lift	€ 125,000	per piece	1	0	1	2
Slider table	€ 75,000	per piece	3	0	3	6
Conveyor	€ 25,000	per 10 metre	3	0	9	12
ETV	€ 300,000	per piece	1	0	1	2
ETV rail	€ 90,000	per 30 metre	1 (1.5)	0	1 (1.5)	2 (3)
Rack	€ 200,000 (x 1.5)	per layer per alley	1	1	1	6 (4)
Box sleds	€ 20,000 (x 1.5)	per layer per alley	1	1	1	6 (4)
Landside portal crane	€ 200,000	per piece	1	0	1	2
Total equipment cost at 3 layer layout			€1,535,000	€220,000	€1,385,000	€3,800,000
Total equipment cost at 2 layer layout			€1,690,000	€330,000	€1,540,000	€3,890,000

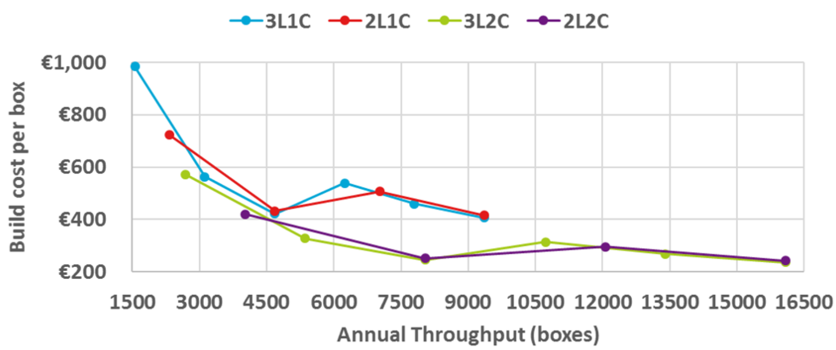


Figure 9.3: Investment cost per annual throughput volume in boxes for 2 and 3 layer (2L&3L) under conditions of 1 or 2 calls per week (1C&2C)

[2]Figure 8.9 demonstrated that the required quay area depth is 15 meters and landside area depth is 25 meters in total.

The numbers between the brackets are used to make these calculations for a case in which two-layer storage is applied. Note that the two-layered layout uses alleys of 45 metres instead of 30 metres. The last row of Table 9.6 indicates the investment costs for equipment in this case. Figure 9.3 illustrates that the costs can vary, depending on whether the call frequency is once or twice per week. The desired terminal layout is primarily dependent on the growth scenario. Although the capacities of both terminals are equal when using one or two full alleys, the costs are not the same. Additional rail length makes the two-layered design more expensive. The lower storage height has no benefits in terms of costs for these cases.

The first case is an investor who forecasts a growth pattern that demands storage of either 20/40/60 boxes. In these cases, the three-layered design will allow for minimal investment under all conditions. Each layer contains 20 box slots, which makes the scalable capacity follow the forecast precisely. The 2L design will mean that the capacity exceeds the demand, leading to excess costs during the first two steps. When the demand is 20 box slots, the first layer offers 30 slots, leading to an occupancy of 66.7%. At 40 boxes of demand, the second layer is required, leading to 60 present slots and a similar occupancy of 66.7%. The 2L design with one alley is only optimally equipped at 60 boxes.

The opposite also applies, which means that for a scenario of 30/60 boxes, the 2L design is optimally equipped while the 3L design starts with abundant capacity at the first period. What terminal design should be pursued must therefore be determined based on the transport case.

Apart from this equipment investment, the terminal development also requires investment in the area, quay strengthening, fences, and other miscellaneous expenses. These costs are estimated and depicted in Table 9.7. This also demonstrates that the 2L design is €112,500 more expensive than the 3L design. The reasons for using the small-scale and rural terminal were the low costs and low ground costs. When ground prices rise steadily, demand for cheaper locations also increases. A detailed area cost analysis is beyond this stage of design, but brief research has indicated that prices in the rural Netherlands range between €60-€85 per m^2. The site will also require strengthening and foundation work.

Table 9.7: Other investments for the SCHC concept

Expense	Amount	Unit	Required investment	
			3L lay-out	2L lay-out
Area	€750,000	per ha	€525,000	€637.500
Quay	€100,000	per berth	€100,000	€100,000
Fence	€250	per metre	€65,000	€67,500
Miscellaneous	€50,000	per ha	€50,000	€50,000
Total			€740,000	€855,000

The running costs of the terminal include energy, ICT, overhead, R&M, rent, and miscellaneous expenses. Energy is estimated with equation 9.3. The terminal will be fully electric and more efficient than existing ITs, which reduces the annual energy cost to levels below the reference estimates of Wiegmans and Konings [2015] and Smid et al. [2016]. Overhead, ICT, and miscellaneous costs are estimated based on personal insight. Annual repair and maintenance of equipment follows the assumptions provided in Table 8.5. Other terminal R&M is expected to add up to €50,000 per annum. Than adding all this together leads to the following annual operational costs for six different terminal sizes.

$$\text{Energy Expenses} = €25,000 + (€10,000 \cdot \text{number of layers}) \cdot \text{number of alley's}. \tag{9.3}$$

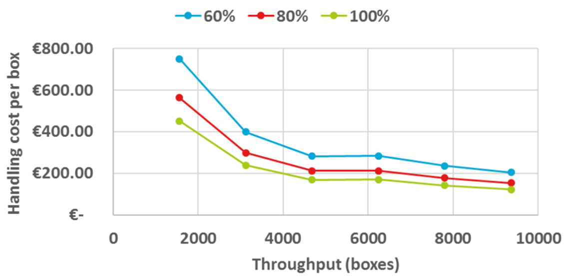
This information enables the determination of the operating cost per box. Figure 9.4 illustrates the cost per box for the six terminal sizes and two frequencies for the 3L layout and four terminal sizes and two frequencies for the 2L layout. Note that the axes of all figures differ.

Results indicate that the terminal designed for one call per week can attain the lowest cost of €125 per box at maximum capacity (9,400 boxes / 15600 TEU). Costs do not decrease between 4,500 and 7,000 boxes per year due to the second required alley. These figures are significantly above the industry-accepted handling cost of ≈ €83.33 that was described in chapter 5.

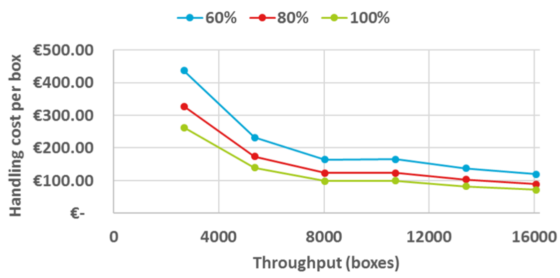
The two calls per week alternative has substantially lower costs because the terminal equipment is more efficiently used, and less equipment is required for the same annual throughput. At maximum capacity, costs can come down to ≈ €72 per box (16,080 boxes / 26,800 TEU). Between 8,000 and 11,000 boxes per year, costs barely decrease. This is still above industry values but is substantially more acceptable.

The concept terminal costs already outperform current small-scale terminals of 20,000 TEU capacity (≈ €117 at 12,000 boxes). At 13,300 TEU, the concept terminal alternative already operates at lower costs than the current market competition can achieve at maximum utilisation.

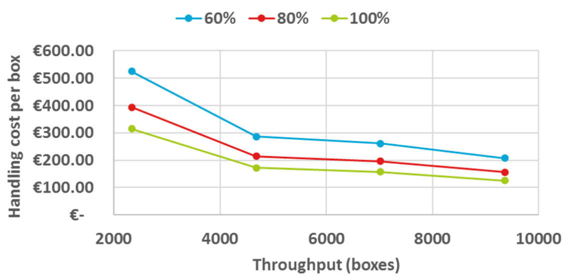
If the SCCC can generate enough margin to accept higher handling costs at the small-scale terminal, the earliest feasibility will be achieved at two calls per week. This enables the most efficient usage and thereby minimises costs. The lower cost will already have an effect on cash flow in the start-up phase of the terminal.



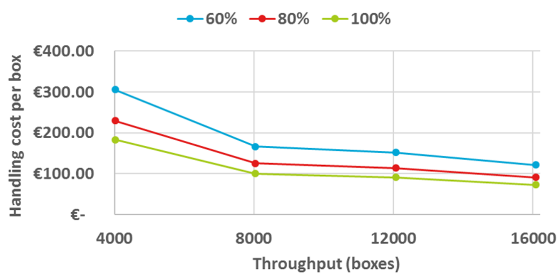
(a) One call per week with three layers (3L1C)



(b) Two calls per week with three layers (3L2C)



(c) One call per week with two layers (2L1C)



(d) Two calls per week with two layers (2L2C)

Figure 9.4: Handling cost for three different degrees of utilisation for both one and two calls per week and terminal layout consisting of three and two layers.

Analysing the results from figure 9.4 indicates that size does matter. At low annual throughput, inbound and outbound costs are very high. Note that chapter 5 found a current market average handling cost of €83.33. While the data that was used for figure 9.4 is partially based on the capital expenses, that data should be interpreted as the operating costs of a terminal of that size. In reality, an upfront investment will be made that requires repayment, and those future repayments should be discounted from present values. This will mean that forecast earnings in the future are less valuable than they seem at first impression. A net present value calculation is made to prevent this mistake.

Sub-figures 9.4b and 9.4d indicate that for 12,000 boxes (20,000 TEU for FEU:TEU = 1.67), costs come down to levels below €100 per box. However, these costs are the operating costs for a terminal in year X. Although the values in sub-figures 9.4b and 9.4d are difficult to read, the cost of the 3L terminal is lower than the 2L alternative. This is caused by the additional ETV rail length required when using lower and longer alleys. The result is that the NPV calculations are only made of the 3L design.

Investments in the equipment and terminal area are depicted in Table 9.8. It is estimated that the terminal will be 80% written off in 10 years, leaving a residual value (RV) of 20%. One advantage of this fast depreciation is that less taxes are due because depreciation may be subtracted from the results before tax. Financing is performed with a 60/40 split between bank and personal funds. This is in line with the start-up guide for inland shipping [Mercurius schipping group, 2018]. Six percent of interest costs are calculated for a previously-calculated weighted average cost of capital (WACC).

Table 9.8: Investment, remaining value (RV) and capital origin.

Capacity		1560	3120	4680	6240	7800	9360
Capacity		2680	5360	8040	10720	13400	16080
Layers		1	2	3	4	5	6
Equipment		€1,535,000	€1,755,000	€1,975,000	€3,360,000	€3,580,000	€3,800,000
Other		€685,000	€685,000	€685,000	€685,000	€685,000	€685,000
Investment		€2,220,000	€2,440,000	€2,660,000	€4,045,000	€4,265,000	€4,485,000
RV equipment	20%	€307,000	€351,000	€395,000	€672,000	€716,000	€760,000
RV other	20%	€137,000	€137,000	€137,000	€137,000	€137,000	€137,000
Bank loan	60%	€1,332,000	€1,464,000	€1,596,000	€2,427,000	€2,559,000	€2,691,000
Equity	40%	€888,000	€976,000	€1,064,000	€1,618,000	€1,706,000	€1,794,000

This analysis assumes that the bank loan is fully repaid in 10 years because the high-risk profile demands fast repayment to reduce the exposure of the lender. The throughput over the terminal is assumed to be constant and maximized over the entire 10-year running period. Table 9.9 depicts the resultant valid minimally-attainable cost levels. This table indicates that the terminal that receives one call per week can bring costs down to ≈ €141.00 per box (9,360 boxes per year). When that same terminal is maximally used with two calls per week, the costs are ≈ €82.00 per box (16,080 boxes per year). This is a €59.00 reduction per box. At the limit of 12,000 boxes (20,000 TEU), the terminal with two calls per week has costs of ≈ €105.50 per box.

For three calls and seven calls per week, the costs are ≈ €68.50 and €49.00 per box respectively at maximum terminal capacity. However, in terms of throughput volumes, these costs far outgrow the 20,000 TEU (12,000 boxes) capacity limit proposed earlier. At 12,000 boxes, three calls per week and seven calls per week cost ≈ €101.00 and €73.00 per box respectively.

The results can be varied by selecting different values for the parameters. It is however of limited use to present these calculations here since that is what the Excel tool is for. The tool enables personnel calculations for each scenarios of interest. Performance of the SCCC will discuss the desired throughput of interest and will include relevant NPV calculations for the SCHC.

At annual throughput volumes that equal 12,000 boxes, costs are in the €100 range. Currently, no inland terminal external cost charge is in effect. When an emission tax is enforced, these costs will be directly added to the existing costs. An external cost charge of €5 per TEU will thus increase the costs per box by €8.33, because one box represents 1.67 TEU.

In conclusion, marginal feasibility for the inland terminal operation can be achieved for a handling tariff of €105.50. This is already 26.5% above the current market-accepted handling rate of €83.33 per box (chapter 5). The SCCC and SCHC tandem thus have substantial benefits compared to current market alternatives to justify or make room for a handling rate ≥ €105.

These values all use the throughput capacity as the primary influencing factor. It is therefore useful to revisit the definition of the throughput capacity. It is assumed that the terminal handles a certain number of boxes per year. The unit measure is boxes instead of TEU, because chapter 5 demonstrated that terminal cost allocation is based on moves instead of container weight or size. On average, the terminal is expected to operate as a synchromodal alternative to current truck haulage. This means that the terminal will handle 50/50 splits of inbound and outbound cargo flows. Most terminals provide free storage for a limited amount of days. The purpose of the small-scale inland terminal induces the belief that long-term storage is mitigated with abundant capacity. In addition, semi-aggressive price setting can prevent this kind of excessive storage abuse or can lead to additional revenue.

Each 20-box layer allows of storage up to 20 boxes. However, this does not mean that the terminal allows for calls that maximise at 20 boxes. The single or double landside cranes allow for quick and efficient transhipment without storage necessity. This increases the call size that the terminal can serve. With enough storage and landside transfer capacity, the bottleneck is expected to be located at the hatch coaming gantry crane (HCGC) and quay platform.

The costs provided in Table 9.9 are based on the maximum storage capacity for the dwell time spread depicted in figure 9.2. When the demand for direct throughput is larger than assumed, less storage will be required. The opposite is true for the same storage capacity, where an even higher annual throughput volume can be reached. However, this effect is limited to keep results realistic. The cases in which the terminal is called once or twice per week have been calculated for additional transhipment volumes of +20% and +40%. The results are depicted in Table 9.10.

The results indicate that smaller terminals with lower box storage capacity can be used for similar annual throughput volumes. These smaller terminals are used more efficiently because passing more boxes over the terminal results in lower operating costs. The conclusion that can be drawn is that direct throughput or direct transhipment can limit the required terminal size and thereby lower overall operating costs.

In reality, increasing throughput will put pressure on the landside operations as more trucks will have to call for delivery or retrieval of their container. There is no such thing as a seamless operation where trucks do not have to wait. In reality, some trucks will arrive early and require storage. Some truck manoeuvring space is incorporated within the terminal boundary, as depicted in Figure 8.9 (p. 118). When larger call sizes are operated at the terminal, excessive waiting and nuisance to the environment should be prevented. Incorporating in-house parking spots might also be able to resolve these unwanted effects.

Table 9.9: Minimum required handing rate for break-even operations after 10 year of operation.

Box Slots	Capacity 1 call/week	Discount rate 4%	6%	8%	Capacity 2 calls/week	Discount rate 4%	6%	8%
20	1560	€472.38	€492.70	€514.79	2680	€274.97	€286.80	€299.66
40	3120	€252.58	€263.72	€275.83	5360	€147.02	€153.51	€160.56
60	4680	€179.31	€187.39	€196.18	8040	€104.37	€109.08	€114.19
80	6240	€184.42	€193.57	€203.53	10720	€107.35	€112.68	€118.47
100	7800	€154.09	€161.80	€170.20	13400	€89.69	€94.19	€99.07
120	9360	€133.87	€140.63	€147.98	16080	€77.92	€81.86	€86.14
Box Slots	Capacity 3 calls/week	Discount rate 4%	6%	8%	Capacity 7 calls/week	Discount rate 4%	6%	8%
20	3200	€230.29	€240.19	€250.96	4480	€164.49	€171.57	€179.26
40	6400	€123.13	€128.56	€134.47	8960	€87.95	€91.83	€96.05
60	9600	€87.41	€91.35	€95.64	13440	€62.44	€65.25	€68.31
80	12800	€89.90	€94.37	€99.22	17920	€64.22	€67.40	€70.87
100	16000	€75.12	€78.88	€82.97	22400	€53.66	€56.34	€59.27
120	19200	€65.26	€68.56	€72.14	26880	€46.61	€48.97	€51.53

Table 9.10: Minimum required handing rate for break-even operations after 10 year of operation with additional throughput of 20 and 40 percent.

Box Slots	Cap. +20% 1 call/week	Discount rate 4%	6%	8%	Cap. +40% 1 call/week	Discount rate 4%	6%	8%
20	1872	€393.65	€410.59	€428.99	2184	€337.42	€351.93	€367.71
40	3744	€210.48	€219.77	€229.86	4368	€180.41	€188.37	€197.02
60	5616	€149.42	€156.16	€163.48	6552	€128.08	€133.85	€140.13
80	7488	€153.68	€161.31	€169.61	8736	€131.73	€138.27	€145.38
100	9360	€128.41	€134.84	€141.83	10920	€110.06	€115.57	€121.57
120	11232	€111.56	€117.19	€123.31	13104	€95.62	€100.45	€105.70
Box Slots	Cap. +20% 2 calls/week	Discount rate 4%	6%	8%	Cap. +40% 2 calls/week	Discount rate 4%	6%	8%
20	3216	€229.14	€239.00	€249.71	3752	€196.41	€204.86	€214.04
40	6432	€122.52	€127.92	€133.80	7504	€105.02	€109.65	€114.69
60	9648	€86.98	€90.90	€95.16	11256	€74.55	€77.91	€81.57
80	12864	€89.46	€93.90	€98.73	15008	€76.68	€80.48	€84.62
100	16080	€74.74	€78.49	€82.56	18760	€64.07	€67.28	€70.76
120	19296	€64.94	€68.21	€71.78	22512	€55.66	€58.47	€61.53

9.5. SCCC: Cost of Operation

This section will contain the cost performance of the third individual transport chain shackles: SCCC performance.

9.5.1. SCCC Sailing Performance

The vessel performance directly affects the cost of navigation and forms the first shackle of primary importance. The first important annotation is the incorporation of the detour factor. Appendix P contains additional information about the assumed detour factor and the IWT distance multiplier of 1.2. The sailing performance data is translated to truck distance for comparison. A 240km sailing distance thus translates to a 200km truck distance.

The basis for the SCCC is a set of 30 different vessels. The XYZZ models have their own strengths and weaknesses. Chapter 7 covered all the relevant design parameters. All transport cost-influencing factors have been appointed. The result has been incorporated in the previously-mentioned Excel tool to allow all SCCCs to be researchable. It is however too cumbersome and unnecessary to present the results here; the tool should be used for that purpose. The following proposed subjects are of interest:

- The effect of economies of scale (EoS) within the SCCC range. Assuming full ships, how much is cost effected between the 3210 and 3213 types?
- The effect of sailing at partial loading. What happens to the cost of transport when the business model was based on a 3409 but in reality only 50 or 75 percent of the cargo is ultimately attracted ? What are the costs if the 3209 and 3309 types are used for those call sizes?
- The effect of sailing speed. The 2210 type can operate different speeds, which can result in different sailing durations per roundtrip. How does this affect the cost?
- The effect of the sailing regimen. For the case of the 2312 type, the sailing regimes A2 and B are both assumed to be feasible. However, what regimen should be adhered to, and how is this dependent on sailing distance, for instance?

These four cases will result in the full understanding of the performance of the SCCC. The acquired knowledge and insight can then be used to propose a most-favourable case that answers the main question for this study.

All the costs presented in this section are for a TEU container. In shipping, it is common practice to calculate in TEU-equivalent units. When a cargo owner ships a FEU, the 40-foot container will fill two TEU slots, which leads to double costs for sailing. Different factors are applied for High-Cube and 45-foot containers.

9.5.2. SCCC: Economies of Scale

The 3210, 3211, 3212, and 3213 types were selected for the search on EoS within the SCCC series. The following assumptions are made to prevent clouded results. The crewing scheme B is used, which entails the fully-continuous operation of 24 hours every day. The vessels will sail for 50 weeks a year. The average loading degree is 80%. The sailing speed is fixed at a 15km/h average navigation speed.

A single voyage distance of 400 km and 800 km is researched on sailing scheme B. The 400 km translates to 480 km of inland shipping distance and 20km of ARA collection. In total, this distance can be navigated in less than 5 days. Sailing 960 km takes slightly less than 7 days, which makes optimal use of the available days per week.

Table 9.11 depicts the four types, their carrying capacity at 80% loading degree, and the resultant sailed volume per annum. As expected, the annual sailed volume of the 3213 type (6,240 TEU) is 30% more than that of the 3210 type. Appendix Q contains tables with the total annual expenses per cost factor and the resulting costs per TEU per voyage.

The resulting costs are the out-of-pocket cost for the sailing operation, including the time, risk & reliability, and external cost. Table 9.12 contains the absolute and relative values for the four cases at a 480 km sailing distance. Note that the capacity steps between the columns are 10% per column. The 3211 type transports 10% more TEU than the 3210 type. The 3212 and 3213 types are 20% and 30% bigger respectively.

For the OOP, costs decrease with 14% at maximum, while the capacity increases with 30%. Table 9.12 provides a more detailed depiction of how this is caused. Time is deemed irrespective of size; therefore, EoS are unaffected. Risk and reliability (R&R) are related to the day cost. The larger vessels are more expensive and have therefore higher daily cost. However, capacity increases faster than the daily cost, therefore reducing the R&R. Similar reasoning applies to the external cost. The pollution and external effects increase, but the capacity outgrows this increase, effectively reducing the external cost per TEU. A FEU container takes up double the space aboard; therefore, it has double the TEU cost for all factors.

If the four SCCCs sail 960 km, the economies of scale are the same. The percentage point differences are caused by rounding effects. Appendix Q details the out-of-pocket cost for this case in greater detail in Tables Q.2a and Q.2b.

Table 9.11: Sailed capacity for four different SCCC 32ZZ models.

SCCC Type	Capacity at 80%	Sailed volume at 400km and 800km TEU (boxes) per annum
3210	48.0 TEU	4,800 (2,880)
3211	52.8 TEU	5,280 (3,168)
3212	57.6 TEU	5,760 (3,456)
3213	62.4 TEU	6,240 (3,744)

Table 9.12: Absolute and relative generalised cost breakdown for four different SCCC at 480km sailing distance and 80% loading degree. Numbers are TEU specific.

SCCC Type	3210	3211	3212	3213	3210	3211	3212	3213
OOP	€254.09	€242.93	€229.74	€218.98	100%	96%	90%	86%
Time	€45.15	€45.15	€45.15	€45.15	100%	100%	100%	100%
R&R	€43.15	€42.35	€41.41	€40.64	100%	98%	96%	94%
EC	€41.25	€41.19	€39.34	€37.96	100%	100%	95%	92%
GC (excl.)	€342.39	€330.43	€316.30	€304.77	100%	97%	92%	89%
GC (incl.)	€383.64	€371.61	€355.63	€342.73	100%	97%	93%	89%

Table 9.13: Absolute and relative generalised cost breakdown for four different SCCC at 960km sailing distance and 80% loading degree. Numbers are TEU specific.

SCCC Type	3210	3211	3212	3213	3210	3211	3212	3213
OOP	€344.06	€327.14	€308.31	€292.93	100%	95%	90%	85%
Time	€58.05	€58.05	€58.05	€58.05	100%	100%	100%	100%
R&R	€73.58	€72.37	€71.02	€69.92	100%	98%	97%	95%
EC	€72.79	€72.45	€69.49	€67.35	100%	100%	95%	93%
GC (excl.)	€475.69	€457.56	€437.38	€420.90	100%	96%	92%	88%
GC (incl.)	€548.48	€530.01	€506.86	€488.25	100%	97%	92%	89%

When trying to distil a correlation between capacity growth and cost, it can be concluded that a 10% capacity increase leads to a cost reduction of 5% for the out-of-pocket expenses. Time-bounded costs are irrespective of vessel size. Risk and reliability charges decrease by 2% or less for a 10% capacity increase. External cost results are contaminated by rounding assumptions that are deeper in the model. The external cost of the 3211 type is equal to those of the 3210 type. The result for the other two SCCCs supports the assumption that the relative EC values for the 3211 type should be in the range of 97% to 98% of the 3210 type.

Overall, the generalised cost approximately decreases by 4% when the capacity grows by 10%. In case the loading volumes have been growing or are expected to significantly grow, costs can be reduced by switching to a vessel that is as large as possible. The boundaries are the available container volume and the navigation of restrictions.

9.5.3. SCCC: Loading Degree

The second variation of interest is the effect of different loading degrees. If a business is started with the goal of a fully-utilised 3409 type, the eventual cargo load may fall short of expected volumes. The consequence may be that the large vessel sails at partly-loaded conditions. To test the effect of partial loading, the 3409 type's loading degree varies between 100% to 75% to 50%. With the scalability of the SCCC, the 75% capacity automatically corresponds to the 3309 vessel. This vessel allows three-tier stacking instead of four-tier stacking, and since three-fourths equal 75%, this vessel will be fully loaded. Similar parallels can be drawn between the 3409 and 3209 types.

The case consists of 300 km single-distance navigation at a 15km/h average speed. The vessels are operated at scheme B. The sailing time is 5 days. The port collection distance is 20 km.

Appendix R provides the results of the out-of-pocket cost calculations in detail. Table 9.14 below indicates the resulting absolute and relative generalised cost breakdown. As expected, the impact of a lower-loading degree between 100% and 75% is less than lowering from 100% to 50%. This is the result of the concave EoS trend of the cost over the capacity.

Comparisons in terms of generalised costs first produces the observation that the EoS are lost at partial loading conditions and with smaller vessels. Comparing the 3409 type at part load with the smaller SCCC at full load demonstrates that the difference is significant. The large vessel that operates at part load is more expensive than a smaller vessel at full load. At part-load conditions, the costs must be divided over a smaller amount of cargo, leading to higher costs per container. The same mechanism that leads to EOS between small and large vessels also leads to increased costs at partial loading conditions. At full load conditions, there is no such thing as excess costs that have to be divided over the load.

Table 9.14: Absolute and relative generalised cost breakdown for three different SCCC at 300km sailing distance and variable loading degrees. Numbers are TEU specific.

SCCC Type Load. deg.	3409 100%	3409 75%	3309 100%	3409 50%	3209 100%	3409 100%	3409 75%	3309 100%	3409 50%	3209 100%
OOP	€95.67	€122.18	€118.17	€176.93	€166.13	100%	128%	124%	185%	174%
Time	€45.15	€45.15	€45.15	€45.15	€45.15	100%	100%	100%	100%	100%
RR	€25.57	€28.22	€27.82	€33.69	€32.61	100%	110%	109%	132%	128%
EC	€23.63	€27.31	€24.24	€35.70	€27.54	100%	116%	103%	151%	117%
GC (excl.)	€166.39	€195.55	€191.14	€255.77	€243.89	100%	118%	115%	154%	147%
GC (incl.)	€190.01	€222.87	€215.38	€291.46	€271.43	100%	117%	113%	153%	143%

The results indicate a strong preference for fully or near maximally-loaded operations. Transport costs quickly rise at partial loading conditions. A large vessel that operates at partial loading conditions will be more expensive compared to a smaller vessel that operates at full or nearly-full conditions.

The difference between the partially-loaded large vessel and fully-loaded vessel is not negative. During the start-up phase of a new inland container, service cargo volumes will begin at zero. If the investor is careful, risk averse, and persists in investing in a smaller vessel, his/her start-up losses may be minimised and optimal operation is quickly reached. A competitor who is aiming for the long run may operate at slightly higher costs during the same start-up phase but will have the possibility to continue to grow and expand. This will enable the competitor to lower costs and thereby increase their competitiveness and profit.

If the first investor invests in the 3209 type, and the competitor decides to risk it and buy the 3409 type during the first year, the competitor will have higher costs (185%/174% = 6.3% higher costs). During the second year, costs will already be 26.4% lower (128%/174%). Operating both at full capacity will mean the competitor has 74% lower out-of-pocket expenses. Although expenses will be higher during the first years, these additional expenses will be worth it in later years of operation.

Choosing the right size is thus essential. Too big means partial loading operations and unnecessarily high costs of operation, reducing competitiveness. Too small will prevent the owner from ever reaching low-cost operations.

9.5.4. SCCC: Sailing Speed

The third degree of freedom incorporated in the model is that of the navigation speed or average sailed speed. Chapter 3 introduced the operational expenses of inland shipping. Labour is hired per day, fuel is burned depending on the sailing conditions, and the cost of capital is spread over the sailed days. This can be compared to the call-out costs seen in truck haulage.

The sailing speed is one of three main parameters that decide the effective range. Additional factors that affect the navigable range per period include the handling times at ARA and IT as well as the additional waiting times.

For instance, figure 9.1c demonstrated that under sailing condition A1 and 250 kilometres of range, the roundtrip duration was less than a week for average speeds ≥ 15 km/h. When the average sailed speed drops below 15 km/h, the roundtrip cannot be made within 70 hours; the maximum weekly working hours for sailing condition A1 is 5 days of 14 hours each. A 2-day rest period increases the roundtrip duration from just over 5 full days to 8 working days. A weekly operating scheme cannot be achieved, which reduces the effectiveness of the vessel.

Objectives other than making the roundtrip within 1 or 2 weeks are also of importance. As mentioned in Section 9.4, the largest SCCC 3413 can transport a TEU volume of 15,600 pieces per year on 50 operational weeks, undertaking 50 fully-loaded round trips. When the distance increases to the extent that the roundtrip duration exceeds 1 operational week, different conditions require different actions.

In the case of SCCC type 2210 operating under sailing regimen A2, the effect of average navigating speed is borne out. The first case consists of 360 km of single voyage sailing distance. The speeds range from 13km/h to 18km/h. Do note that this is the average assumed navigating speed with 3km/h of current. Upstream, the speeds will range from 10km/h to 15km/h, while downstream the speeds are 3km/h above the average downstream.

The operating cost for the vessel is calculated at 360km of sailing distance, 20km collection distance in the ARA port, and some time for handling at both ends. Appendix S indicates the operating expenses in detail. Table 9.15 provides the generalised cost breakdown for the six different speeds.

The results demonstrate that the sailing takes 5 days for speeds between 13km/h and 16km/h. Rounding up to full days is conducted for factors such as labour cost. Hiring and paying crew for 4.33 days will not occur, but a day rate will be active. At higher speeds, an entire operating day is gained, thereby lowering the OOP cost. The OOP costs for 17km/h decrease from the OOP cost at 16 km/h due to a decrease in labour cost. This decrease outperforms increases in additional fuel.

Under the assumption of navigating for full days, the optimal strategy is to sail as slow as possible while arriving on the same day. When the roundtrip may take 5 days, generalised costs indicate that sailing at 13km/h on average is most efficient. From the perspective of external cost reduction, slow sailing is also worth considering. For example, increasing the optimal speed of 13km/h to 15km/h results in 10% more external costs.

Table 9.15: Generalised cost breakdown for six different sailing speeds at 360km sailing distance for an 80% loaded *'2210'* SCCC. Numbers are TEU specific.

	5 days sailing time				4 days sailing time	
Sailing speed	13km/h	14km/h	15km/h	16km/h	17km/h	18km/h
OOP	€258.23	€261.44	€266.50	€272.10	€267.83	€274.11
Time	€45.15	€45.15	€45.15	€45.15	€38.70	€38.70
RR	€44.82	€45.14	€45.65	€46.21	€45.78	€46.41
EC	€43.11	€44.82	€47.51	€50.49	€53.45	€56.79
GC (excl.)	€348.20	€351.73	€357.30	€363.46	€352.31	€359.22
GC (incl.)	€391.32	€396.54	€404.81	€413.96	€405.77	€416.01
OOP	100%	101%	103%	105%	104%	106%
Time	100%	100%	100%	100%	86%	86%
RR	100%	101%	102%	103%	102%	104%
EC	100%	104%	110%	117%	124%	132%
GC (excl.)	100%	101%	103%	104%	101%	103%
GC (incl.)	100%	101%	103%	106%	104%	106%

The previous case discussed the sailing distance allowing for weekly operations irrespective of speed. Additional challenges arise when the distance between the origin and destination is 480 km. At speeds of ≤ 15km/h, sailing will be so time consuming that no full roundtrip can be made within 5 working days; the roundtrip will increase to 8 days. When a fixed frequency of one call per week is necessary, a second vessel will be required in the case of sailing speeds ≤ 15km/h. The effective annual transported volume per vessel halves as a result. Although the variable costs per annum are lower for a slow-sailing vessel, the fixed costs remain the same. As the transported volumes are halved, out-of-pocket costs substantially increase and become higher than those of a faster sailing vessel.

Table 9.16 demonstrates that the cost per TEU drastically decreases between 15km/h and 16km/h of operating speed. Operating the vessel at speeds ≥ 16km/h is therefore more cost efficient than operating at speeds ≤ 15km/h. Table S.2 illustrates the SCCC annual operating cost and the per-transported TEU resulting cost. These results are for a roundtrip that takes 8 days, leading to an idle period of 6 days because the vessel can only operate full-week services.

Table 9.16: Absolute and relative generalised cost breakdown for six different sailing speeds at 480km sailing distance for an 80% loaded *'2210'* SCCC. Numbers are TEU specific.

Sailing speed	13km/h	14km/h	15km/h	16km/h	17km/h	18km/h
OOP	€453.63	€457.85	€464.38	€286.85	€294.14	€301.95
Time	€64.50	€64.50	€64.50	€45.15	€45.15	€45.15
RR	€47.68	€47.89	€48.22	€53.68	€54.41	€55.19
EC	€53.32	€55.57	€59.04	€62.92	€66.80	€70.95
GC (excl.)	€565.81	€570.24	€577.10	€385.68	€393.70	€402.29
GC (incl.)	€619.13	€625.82	€636.14	€448.60	€460.50	€473.24
OOP	100%	101%	102%	63%	65%	67%
Time	100%	100%	100%	70%	70%	70%
RR	100%	100%	101%	113%	114%	116%
EC	100%	104%	111%	118%	125%	133%
GC (excl.)	100%	101%	102%	68%	70%	71%
GC (incl.)	100%	101%	103%	72%	74%	76%

Results change when the assumption about full week operations is changed to a fully-continuous operation in which the vessel sails for the most days possible irrespective of its roundtrip duration. The roundtrip takes 8 days at speeds ≤ 15km/h. This time, the SCCC is assumed not to wait for the next week; instead, it will immediately set sail on the 9th day to start its next roundtrip. The result is that the vessel will operate an irregular call scheme.

The effect of this approach is that a roundtrip takes 8 days at the lower speeds. At 50 operational weeks, vessels can make 43.75 roundtrips, whereas a week-sailing SCCC (with speed ≥ 16km/h) can make 50 roundtrips. The transported amount of TEU is not halved; instead, it experiences a reduction of -12.5%. The figure of 3,200 TEU then becomes 2,800 TEU transported per annum.

$$\text{Sailed volume reduction} = \frac{43.75}{50} \cdot 100\% - 100\% = -12.5\% \tag{9.4}$$

Table 9.17 indicates the results. For the speeds of more than 16km/h in the last three columns, nothing has changed and they are the same as the values in 9.16. The first three columns have reduced values compared to the table before because the vessel is more effectively operated.

However, since the vessel makes less round-trips per annum, the relative fixed cost pressure per TEU is higher. This effect is so substantial that the slower-sailing SCCC will be more expensive than a faster-sailing SCCC. One key point to be highlighted is that of the external cost, which is lower because sailing at lower speeds is less energy-intensive.

Table 9.17: Absolute and relative generalised cost breakdown for six different sailing speeds at 480km sailing distance for an 80% loaded *'2210'* SCCC with every available day used for navigation. Numbers are TEU specific.

Sailing speed	13km/h	14km/h	15km/h	16km/h	17km/h	18km/h
OOP	€320.35	€324.58	€331.10	€286.85	€294.14	€301.95
Time	€64.50	€64.50	€64.50	€45.15	€45.15	€45.15
RR	€47.68	€47.89	€48.22	€53.68	€54.41	€55.19
EC	€46.66	€48.63	€51.66	€62.92	€66.80	€70.95
GC (excl.)	€432.53	€436.97	€443.82	€385.68	€393.70	€402.29
GC (incl.)	€479.19	€485.59	€495.48	€448.60	€460.50	€473.24
OOP	100%	101%	103%	90%	92%	94%
Time	100%	100%	100%	70%	70%	70%
RR	100%	100%	101%	113%	114%	116%
EC	100%	104%	111%	135%	143%	152%
GC (excl.)	100%	101%	103%	89%	91%	93%
GC (incl.)	100%	101%	103%	94%	96%	99%

In conclusion, it is beneficial to sail as slowly as possible if the roundtrip duration stays the same in terms of days. As soon as the roundtrip starts to exceed one full week of operation, it is beneficial to increase the speed to reduce the operating cost. The SCCC can then keep making weekly round trips and be used in an optimal operating scheme. However, it is also beneficial to increase the speed to be just sufficient to avoid the weekend penalty.

The last three columns of Table 9.17 demonstrate that increasing the speed is sufficient to prevent the weekend penalty. Increasing the speed to 18km/h where possible will mean additional OOP costs of €15 per TEU. The generalised costs that include the external factors become €25 per TEU higher.

The difference in generalised cost between slow navigation and taking the weekend penalty is less than €6 per TEU.

9.5.5. SCCC: Sailing Regimen

The last variation that is used to research the cost performance of the SCCC is the sailing regimen. Subsection 7.5.1 discussed the most common operational profiles. Subsections 9.3.1 and 9.3.2 argued that the sailing scheme has a significant effect.

The first analyses consist of a 2312 type that is operated at either A2 or B. This type sails distances of 300 km, 600 km, and 900 km at speeds of 16km/h and an 80% loading degree. Under the assumption of irregular call acceptance, the vessels sail as much as possible according to the rules. The results of the operational expenses are illustrated in appendix T (Table T.1). The table below provides the generalised cost breakdown.

The results clearly indicate that under the 80%-loaded conditions, the costs of sailing scheme B are lower than regimen A2. More working hours per day for B means that more distance will be covered per day. Fully-continuous navigation can take place with a week that has 7 work days. At 300 km sailing distance, the vessel can make double the amount of annual calls and thereby transport twice as many TEU. The fixed cost stays the same, no matter which sailing regime is in action. Doubling the cargo therefore effectively halves the fixed cost per TEU. This effect outweighs the additional labour and fuel costs.

Table 9.18: Absolute and relative generalised cost breakdown for two different sailing regimens (A2 & B) at three different sailing distances for an 80% loaded *'2312'* SCCC with every available day used for navigation. Numbers are TEU specific.

Sailing regime	A2	B	A2	B	A2	B
Distance	300km	300km	600km	600km	900km	900km
OOP	€185.75	€155.13	€276.83	€247.55	€374.98	€342.99
Time	€45.15	€38.70	€70.95	€51.60	€90.30	€64.50
RR	€37.58	€41.81	€58.53	€60.35	€76.87	€78.49
EC	€41.56	€41.55	€73.15	€73.14	€104.75	€104.73
GC (excl.)	€268.48	€235.64	€406.31	€359.50	€542.15	€485.98
GC (incl.)	€310.04	€277.19	€479.46	€432.64	€646.90	€590.71
OOP	100%	84%	149%	133%	202%	185%
Time	100%	86%	157%	114%	200%	143%
RR	100%	111%	156%	161%	205%	209%
EC	100%	100%	176%	176%	252%	252%
GC (excl.)	100%	88%	151%	134%	202%	181%
GC (incl.)	100%	89%	155%	140%	209%	191%

Results will differ if the SCCC does not operate at a free call frequency and must follow a fixed scheme. Table T.2 contains the values in more detail. The results of the generalised cost breakdown in Table 9.19 indicate that out-of-pocket costs increase substantially for vessels that operate at A2 and longer distances. The cause for this effect is the roundtrip time, and it corresponds with the multiple of significance in the form of half a week. If the roundtrip distance is 9 days, as in the A2 and 600 km case, it leaves 1.5 days of unused cycle time. In the 900 km case, the roundtrip time is 12 days. This leaves 2 days unused and only allows 25 roundtrips, which negatively influences the transported amount of TEU.

Table 9.19: Absolute and relative generalised cost breakdown for two different sailing regimens (A2 & B) at three different sailing distances for an 80% loaded *'2312'* SCCC with regular navigation only. Regular is a multiple of half a week. Numbers are TEU specific.

Sailing regime	A2	B	A2	B	A2	B
Distance	300km	300km	600km	600km	900km	900km
OOP	€185.75	€156.54	€347.15	€271.46	€452.33	€387.99
Time	€45.15	€38.70	€70.95	€51.60	€90.30	€64.50
RR	€37.58	€41.36	€54.36	€56.39	€73.09	€73.48
EC	€41.56	€41.55	€73.15	€73.14	€104.75	€104.73
GC (excl.)	€268.48	€236.60	€472.46	€379.45	€615.72	€525.97
GC (incl.)	€310.04	€278.15	€545.62	€452.59	€720.47	€630.70
OOP	100%	84%	187%	146%	244%	209%
Time	100%	86%	157%	114%	200%	143%
RR	100%	110%	145%	150%	194%	196%
EC	100%	100%	176%	176%	252%	252%
GC (excl.)	100%	88%	176%	141%	229%	196%
GC (incl.)	100%	90%	176%	146%	232%	203%

9.6. Lessons Learned from SCCC and SCHC

Throughout Parts II and III, insight was gained on the subject of inland container transport, which includes shipping, handling, and pre- and post-haulage. This chapter has provided insight on the considerations when using the SCCC and SCHC. The knowledge and understanding can then be used to research the feasibility of both concepts. This is the subject of the case study in the next chapter.

Section 9.4 indicated that for the scalable terminal concept, there is simply insufficient throughput to divide the costs at very small throughput volumes. The cost curves depicted in Section 5.1 (page 74 Figure 5.8) are also observed at the SCHC. However, the superior scalability and dedicated terminal design for low volumes means that the costs per box at low volumes are substantially below those found at current small-scale terminals.

The costs per box of the terminal decrease quickly as soon as the annual handled volume grows. This effect was already found at existing inland terminals and depicted in figure 5.8 (page 74). With the even greater scalability of the concept terminal, the same curve is found, but the volumes at which the decreased cost effects occur are far smaller. At full capacity (20,000 TEU / 12,000 boxes) and two calls per week, the costs per box are ≈ €105.50. Temporary storage (max 1 week) and landside operations are incorporated in this cost quay operation. At increased direct throughput (excluding storage), the effective terminal capacity increases and the costs per box decrease to ≈ €100.50.

The cost level per box of medium (50,000 TEU) terminals is equal to that of the SCHC with ≈ 16,000 boxes (26,700 TEU). With the advanced scalability, even lower costs of operation for the SCHC could be achieved at locations where expected container flows are even larger.

At the same time, the terminal is more cost efficient at two smaller calls per week than at one large call. This is an interesting finding, especially in light of Subsection 9.5.3. Take a case in which annual demand for transport or supply of containers is present. This volume can be transported by, for example, either the 3409 type at one call per week or two 3209 types that are calling once per week each. Table 9.14 demonstrated that the smaller ships at full load conditions operate at 74% higher OOP costs. The generalised cost, including the external costs, is 43% higher for the smaller vessel compared to the external cost. Table 9.20 compares the costs of both vessels

Table 9.20: Absolute and relative generalised cost breakdown for two different SCCC at 300km sailing distance and full loading degrees. Numbers are TEU specific.

SCCC Type	3409	3209	3409	3209
Load. deg.	100%	100%	100%	100%
OOP	€95.67	€166.13	100%	174%
Time	€45.15	€45.15	100%	100%
RR	€25.57	€32.61	100%	128%
EC	€23.63	€27.54	100%	117%
GC (excl.)	€166.39	€243.89	100%	147%
GC (incl.)	€190.01	€271.43	100%	143%

At 300 km, the difference in OOP costs per TEU is approximately €70 per TEU (€140 per FEU). Increasing the sailing distance will increase this gap as more economies of scale can be reaped by the larger vessel. The total transported volume in this case is 10,800 TEU (6,480 boxes) as the vessel sails 50 times from ARA to IT and 50 times from IT to ARA. Equation 9.6 depicts the calculation that leads to this number.

$$\text{Sailed capacity} = \text{SCCC capacity} \cdot \text{Loading degree} \cdot \#\ \text{calls at both ends} \tag{9.5}$$

$$\text{Sailed capacity} = 3 * 4 * 9 \cdot 100\% \cdot 50 \cdot 2 = 10{,}800\ \text{TEU (6480 boxes)} \tag{9.6}$$

The SCHC handling cost at ≈ 6,480 boxes is approximately €194.50 (one call per week) or €135.50 (two calls per week), depending on the call frequency. These costs are per box and are therefore similar for a TEU, FEU, FEU High-Cube, or 45-foot HC. These statistics demonstrate that the additional call can at most generate a cost reduction of €59.00 per box (€194.50-€135.50).

This cost reduction can be compared to the cost increase of the SCCC when using two vessels instead of one. The additional cost per 20"/40"/40"HC/45"HC is €70/140/140/140 (sailing) minus €59.00 (handling) when using two SCCC 3209 types instead of one 3409 type. The use of two smaller vessels therefore costs €11.00 more per TEU and €82.00 more for other sizes, assuming the HC container was not charged separately or the cost difference would be even greater.

Table 9.21 summarises the previous text in a clear overview that enables easy comparison. The last rows of the table demonstrate that for both TEU and FEU-size boxes and with regard to out-of-pocket expenses only, a large vessel that calls once per week should be preferred over two smaller vessels that call at a higher frequency. The average difference for a box is €58.43 in favour of the 3409 type. For the proposed 6,480 boxes, this difference adds up to €378,626.40.

Table 9.22 compares the generalised cost of the two alternatives and enlarges the difference in favour of the large vessel. This difference between the two alternatives becomes €76.70. Over the 6,480 boxes, this difference adds up to €497,016.00.

The next Chapter applies this knowledge to a potentially feasible business case. Conclusions are first discussed in the next Section.

Table 9.21: Out-of-pocket cost comparison of two transport alternatives. Two smaller vessel versus one large vessel.

SCCC Type	3209	3409
Number of vessels	2	1
Transported volume per vessel per annum	5400 TEU (3240 boxes)	10800 TEU (6480 boxes)
Distance	300km	300km
Loading degree	100%	100%
Sailing cost	€166.13 per TEU €332.26 per FEU €276.88 per box	€95.67 per TEU €191.34 per FEU €159.45 per box
SCHC call frequency	2/week	1/week
SCHC layout	1 alleys, 3 layers	1 alley 3 layers 1 alley 2 layers
Handling cost	€135.50 per box	€194.50 per box
Transport and Handling cost	€301.63 per TEU €467.76 per FEU €412.38 per box	€290.17 per TEU €385.84 per FEU €353.95 per box

Table 9.22: Generalised cost comparison of two transport alternatives with included external cost. Two smaller vessel versus one large vessel.

SCCC Type	3209	3409
Number of vessels	2	1
Transported volume per vessel per annum	5400 TEU (3240 boxes)	10800 TEU (6480 boxes)
Distance	300km	300km
Loading degree	100%	100%
Sailing GC	€271.43 per TEU €542.86 per FEU €452.38 per box	€190.01 per TEU €380.02 per FEU €316.68 per box
SCHC call frequency	2/week	1/week
SCHC layout	1 alleys, 3 layers	1 alley 3 layers 1 alley 2 layers
Handling GC	€140.50 per TEU €145.50 per FEU €143.83 per box	€199.50 per TEU €204.50 per FEU €207.83 per box
Transport and Handling GC	€411.93 per TEU €688.36 per FEU €596.21 per box	€389.51 per TEU €584.52 per FEU €519.51 per box

9.7. Intermediate Conclusions Chapter 9

This chapter discussed a variety of important variables for both the SCCC and SCHC. Section 9.1 and Subsection 9.5.1 introduced these variables, and the subsequent Subsections provided results for different choices. The provided costs for pre- and post-haulage (Section 9.2) cannot be overlooked. The examples of the previous sections are all in the range of €100-€750. The PPH costs are in the same range. These effects were also described to be of significant impact in chapter 6.

The terminal is a pivot point in terms of operations but is less crucial in terms of overall costs. Adequate storage and handling capacity determine the maximum services' throughput volume. A more intensively-used terminal will result in lower costs per box. At the same time, for the very low volumes of ≤ 6,000 boxes (10,000 TEU), costs remain very high even when the terminal is at its smallest at seven calls per week. Hence, volume does matter for lowering the terminal's costs. From the terminal's perspective, the most efficient option would be to increase the call frequency as this leads to increased volume with minimal additional investment required. Direct transhipment also allows the terminal to increase its overall throughput without additional investments. This also substantially reduces the costs per box.

Performance of the SCCC was analysed for four primary parameters. It was found that right vessel size is important for attainable cost levels. A large vessel at partial load is more expensive than a smaller competitor at full load. However, a vessel that is too small will mean that costs cannot come down. This effect is far more substantial, as Table 9.14 demonstrates. Which vessel is the right size depends on the cargo volumes, forecast, and sailing limitations such as bridges.

As the example in Section 9.6 demonstrated, a larger vessel can operate at lower costs than a smaller version. Subsection 9.5.2 demonstrated that a larger SCCC can accumulate substantial economies of scale. This could potentially have a double effect. When the largest possible vessel is operated, costs per unit come down to the minimum level. When costs are as low as possible, the operational margin will be increased, which will allow for lower tariff settings. This in turn increases the attractiveness of the transport service.

Effective range is critical to inland shipping. At sailing regimens A1 and A2, after the fifth day of operating, there is a mandatory 2-day rest period over the weekend. When the single or roundtrip does not reach its destination before this resting period, two additional days are incurred. The result is that either an irregular sailing frequency or less round trips per year can be made or both. Increasing the speed was found to be beneficial if it prevented the weekend delay. At the same time, faster sailing to gain a day (such as a trip taking 4 instead of 5 days) had no pure positive effect on the basic operation of connecting the inland terminal to one of the ARA ports. The extra day could be used to do some relocating work in an ARA port, for instance , leading to additional revenue possibilities. The crane aboard the vessel cannot be used for such operations, which makes the SCCC relatively expensive for that purpose.

In conclusion, vessel size is a major factor in the sailing costs per TEU, while the call frequency and throughput volume are major factors for the costs per box at the terminal. The effect of PPH distance is substantial across the entire chain. An understanding of these effects and the cut-off values for speed, distance, and volumes enable the selection of a favourable case.

10

Researching a Favourable Case

The previous chapter discussed the performance of the individual parts of the conceptual transport alternative. The chapter argued that the terminal would benefit from two calls per week instead of one call. Capacity at two calls is limited, and at the same throughput volume, costs can be reduced to the bare minimum.

On the other hand, the SCCC performance indicated the importance and effect of the EOS within the SCCC series. Using a larger vessel creates EoS that outweigh the additional handling costs. Operating at partial loading conditions significantly increases the cost of transport. However, it was also demonstrated that small and fully-loaded ships could never lower transport costs to those of large vessels. A large vessel at partial load clearly has room for improvement.

Competition was discussed in chapter 6 and the results indicated the strength of the truck in terms of short distance transport. At longer distances, the transport efficiency of the large CEMT Va meant that transport costs were lower than those of a truck. At the same time, PPH distance has a greater effect on the costs of the CEMT Va alternative in terms of OOP, external costs, and generalised costs.

Since the SCCCs are smaller than the CEMT Va competitor, it may be expected that the costs over the medium distance (200-400km) could potentially be competitive. This is particularly true when the SCCC can make use of its limited dimensions and thereby penetrate the capillaries of the network. The SCHC terminal will therefore be closer to the destination.

When the terminal is located closer to the destination, a more rural environment should be selected to reduce the cost for ground and quay. In addition, nuisances will be mitigated or reduced to the bare minimum. Apart from these two effects, the SCHC's location will lead to greater sailing distances, which enables the EoS of the SCCC to be fully internalised. At the same time, the PPH distances decrease, which leads to substantial cost reductions. Since the PPH is performed by an external partner, the greater its share, the lesser the potential profit for the SCCC and SCHC alternatives.

Lowering the PPH distance will reduce the external issues caused by truck haulage such as congestion, accidents, and harmful emissions. For the box to arrive at its destination, external costs are minimised when the SCCC's share is maximised and the required PPH distance is minimised.

10.1. Case Assumptions

Several assumptions are necessary for this case, which are discussed in this section. The case under consideration is of container transport between the Port of Rotterdam and the region around Münster, Osnabrück and Bielefeld in Germany. The rural terminal is located between Münster and Osnabrück on the shores of the Dortmund-Ems canal near the airport Münster/Osnabrück and the city of Ladbergen. The main road A1 is adjacent to the terminal, which allows easy PPH. Figure 10.1 depicts the proposed terminal location on the local, regional, and national level.

A forest plot is selected near the existing bulk terminal, named Hafen Oelrich-Ladbergen, in Ladbergen. Figure 10.1a indicates this plot in dark grey. The maximum site depth is 125 metres and the waterfront length is 180 metres. The 475 road, which is adjacent to the plot, is easily accessible. The distance to the A1 main road is 1.2 kilometres. Currently, more industry is present in the direct neighbourhood of the proposed area; one example is a truck haulage company. Introducing the terminal will not create nuisance for residents. The 475 road that connects the terminal to the A1 does not run across residential areas, meaning that no nuisance is created.

Figure 10.1b illustrates the regional scale of the area; the terminal sits in between Münster (300,000 residents) and Osnabrück (160,000 residents). Both cities are located 25 km from the terminal. The road distances from the city are ≤ 30 km in both cases. The city of Bielefeld (330,000 residents) is 80 km away. At least 850,000 residents are in the smaller towns and cities in the area between Münster, Bielefeld, and Osnabrück. Münster and Bielefeld fall within the state of North Rhine Westphalia, which is the state with the highest gross domestic product (GDP). Osnabrück is just across the state border and is part of Lower Saxony, which is the state with the 3rd highest GDP. Substantial economic activity is thus present in the region.

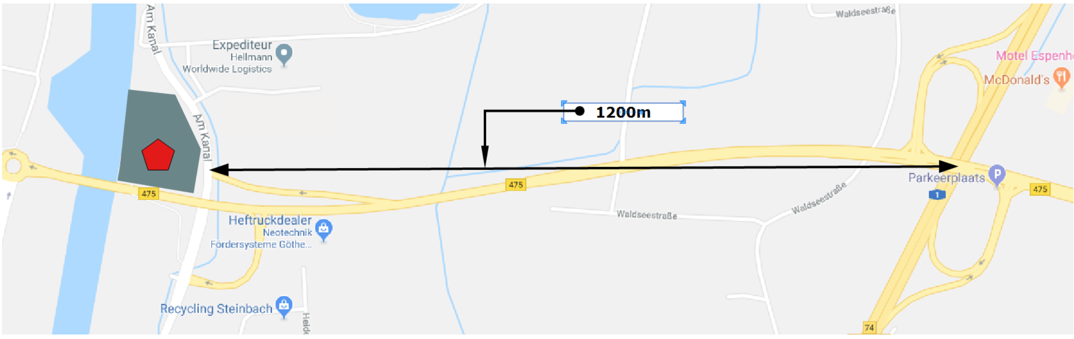
Figure 10.1c illustrates the terminal's location relative to Rotterdam. Rotterdam and the destination are separated by 250km in a straight line. The short navigating path is 340 km. Antwerpen to Ladbergen is 380 km. Amsterdam to Ladbergen is 320 km. All these distances have been calculated with the Blue Roadmap waterway exploring tool [Bureau Voorlichting Binnenvaart, 2014a].

The Dortmund-Ems canal could already be navigated by vessels that are equal to or smaller than CEMT IV (max length (L) x breadth (B) x draught (T) = 86 x 9.6 x 2.8 m). In line with broader trends of European investment in infrastructure, the canal has been upgraded to accept CEMT Va barges up to Dortmund and elongated CEMT IV vessels elsewhere. The primary shortcoming of the canal is the presence of numerous fixed-height bridges. New bridges have been built that are fixed at the same height, which excludes any opportunity for growth with additional stacked layers. The fixed underpass limits the air draught to 5.25 m at regular water levels. Three layers of regular containers can be stored at a maximum draught of 3 metres. In practice, with HC boxes aboard and less draught, the maximum stacking height will be two layers of HC or three layers of regular containers at maximum ballast conditions.

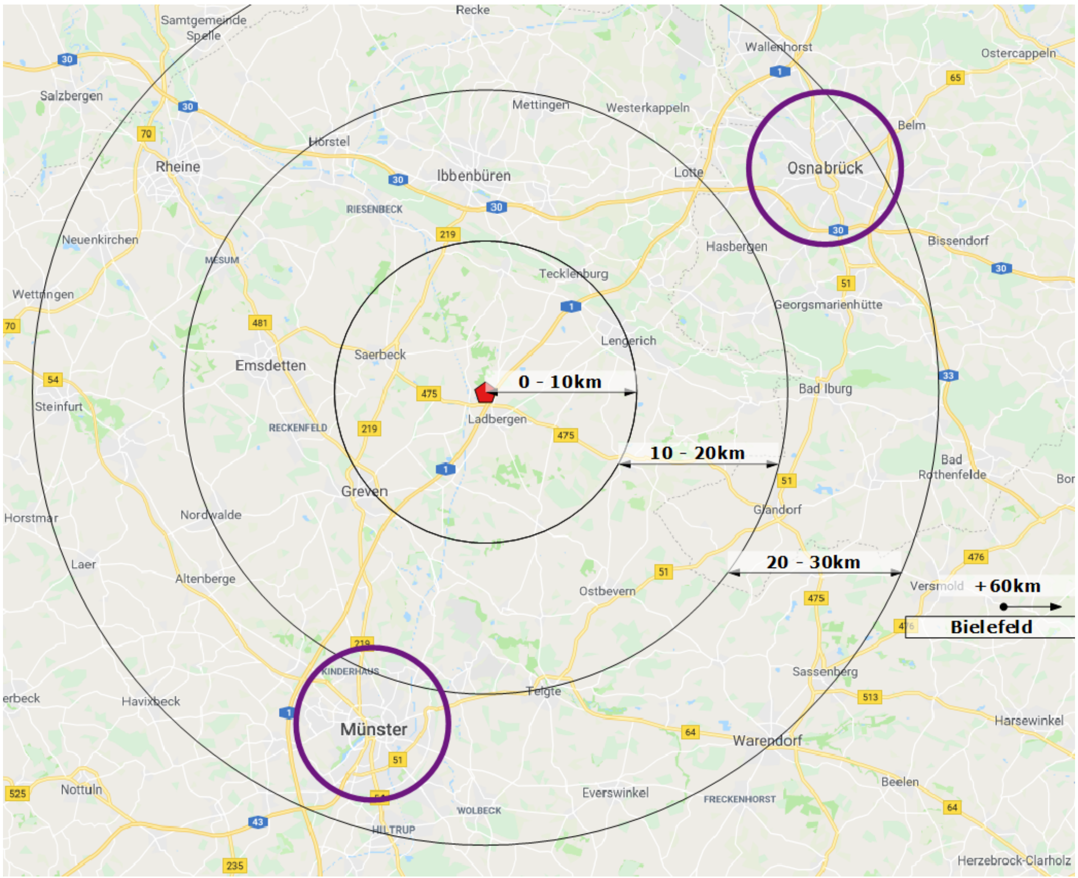
This excludes the 3400 SCCC series for application to the test case. This series will be able to sail at a three-layered configuration at best. Subsection 9.5.3 demonstrated that a 3400 series at a 75% loading degree was more expensive than a 3300 series at fully loaded conditions.

High Cube containers will be transportable at one or two layers only. This effectively reduces the SCCC capacity. Hence, higher costs must be charged for a HC container. When a HC container costs 50% more than a standard height box, it may be assumed that less HCs will be transported than average. This will be further elaborated on later in this chapter.

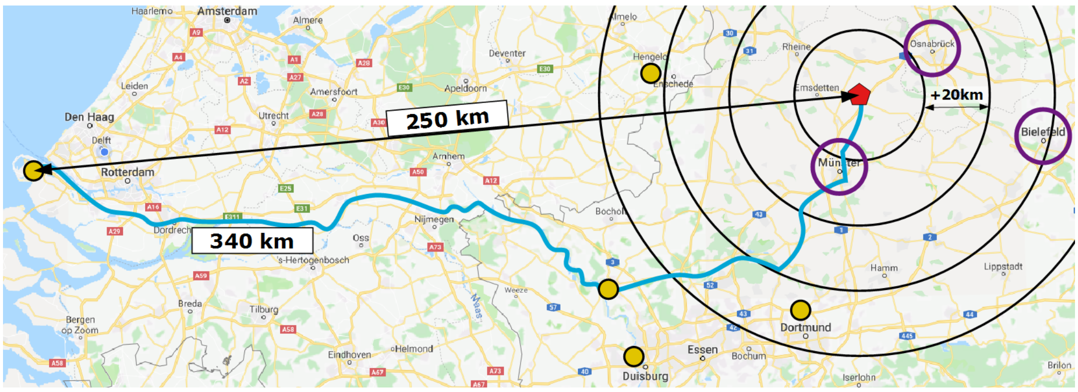
The yellow and orange dots in figure 10.1c indicate existing terminals, which will be addressed in the next subsection. Purple circles indicate the circumference of the three cities. The red pentagon indicates the Ladbergen terminal location.



(a) Possible local terminal location



(b) Regional terminal location. Circles indicate 10km range increments.



(c) National terminal location. Circles indicate 10km range increments.

Figure 10.1: The location of the terminal with respect to its surroundings.

10.1.1. Distances

The distance between the Port of Rotterdam and the concept terminal in Ladbergen is 340 km, and the road distance is 310 km. Alternative or currently-used container terminals can be found in Hengelo (NLD), such as the CTT Terminal. This is accessible via the Dutch inland waterway network. The alternative option along the Rhine is Wesel, which is located at the Wesel-Datteln canal and is accessible by CEMT ≥ Va. Duisburg, the largest inland port, allows the largest ships and is the most important container hub in inland shipping. The last alternative container terminal is located at Dortmund.

The upper part of Table 10.1 provides the truck distances between these hubs and the cities of Osnabrück, Münster, and Bielefeld. The lower part of the table depicts the sailing distance from Rotterdam to any of the possible container terminals.

Table 10.1: Truck and IWT distances between several key points.

	Origin	Destination	Mode	Distance
Direct long haul	Hutchinson ECT Delta	Osnabrück (c)	Truck	330km
		Münster (c)		300km
		Bielefeld (c)		390km
Pre- and Post-Haulage	CTT Hengelo	Osnabrück (c)	Truck	105km
		Münster (c)		80km
		Bielefeld (c)		160km
	Duisburg 3T	Osnabrück (c)		160km
		Münster (c)		110km
		Bielefeld (c)		180km
	Dortmund CT	Osnabrück (c)		120km
		Münster (c)		70km
		Bielefeld (c)		110km
	Wesel	Osnabrück (c)		165km
		Münster (c)		115km
		Bielefeld (c)		175km
	Ladbergen (SCHC)	Osnabrück (c)		30km
		Münster (c)		30km
		Bielefeld (c)		70km
Vessel concept	Hutchinson ECT Delta	Ladbergen Terminal	SCCC	340km
IWT	Hutchinson ECT Delta	Duisburg 3T	CEMT Va+	250km
	Hutchinson ECT Delta	Dortmund CT	CEMT IV	310km
	Hutchinson ECT Delta	CTT Hengelo	CEMT Va	260km
	Hutchinson ECT Delta	Wesel	CEMT Va	230km

The single voyage distance for the SCCC is 340 km. However, additional analysis is required. For example, the Blue Roadmap calculator found that seven sluices must be passed. This leads to 5 hours and 15 minutes of additional time, whereas the previously-assumed value was 2 hours per single distance. In addition, a CEMT IV barge of 105 m length is claimed, by Bureau Voorlichting Binnenvaart [2014a], to have an upstream speed of 10km/h (34 sailing hours for 340 km) and a downstream speed of 12.5km/h. This would mean that the to-be expected current is ≈ 1km/h instead of the assumed 3 km/h. Additionally, the actual speeds are substantially lower than the assumed 13km/h in the slowest case of subsection 9.5.4.

If the ARA handling is estimated to be 24 hours, the IT time is estimated at 8 hours, and the sluices requiring 5 hours and 15 minutes per single direction, this adds up to 42 hours and 30 minutes in total. For a SCCC operating under 'A2', this leaves 47 hours and 30 minutes of sailing time. A SCCC operating under the B scheme will have 125 and a half hours remaining. It is important to remember that sailing regimen A2 allows for 5 sailing days of 18 hours each per week whereas B allows full-continuous operations throughout the week.

In case the current assumptions are brought down from 3 km/h to 1.5 km/h, the required upstream speed becomes 13km/h and the downstream speed becomes 16km/h when a SCCC operating under A2 makes the roundtrip within 1 week. Section 9.5 indicated that increasing the speed and fuel consumption was favourable, while decreasing the speed and incorporating the weekend was not.

10.1.2. Annual Volume

The Osnabrück, Münster, Bielefeld area houses at least 850,000 inhabitants and has a GDP that is among the highest in Germany. Hence, substantial cargo volumes may be expected. Van der Meulen et al. [2018] have forecast a regional growth of transported volume between 2% and 8% for the next 5 years.

Translating this to a forecast for the specific case is difficult because no market study has been conducted. Therefore, a pessimistic assumption will be made. Ziel [2017] has assumed that 31,200 TEU will be present for an area of approximately 320,000 inhabitants. The case area has more than 2.5 times the inhabitants and more economic activity. This would translate to a potential container market size of 80,000 TEU per year.

The residents and business are currently generating an amount of containers to be transported each year. Of this container transport flow, a total of 18,000 TEU is expected to be attractable if the price is right. This forecast is thus very conservative, which increases the likelihood of this minimum amount being attainable. Table 10.2 depicts the proposed transportable volume per year. After year 3, the volume is assumed to remain fixed.

Table 10.2: Transport volume per annum.

Year	TEU:FEU = 1:2 Demand/Supply		TEU:FEU = 1:1 Demand/Supply	
	TEU	boxes	TEU	boxes
0	0	0	0	0
0.5	5,000	3,000	5,000	3,330
1	9,000	5,400	9,000	6,000
1.5	12,000	7,200	12,000	8,000
2	15,000	9,000	15,000	10,000
3	18,000	10,800	18,000	12,000

10.1.3. Best Fitting SCCC

The vessels of the SCCC range, have a maximum annual transported volume of 15,600 TEU, which means that no single vessel in that SCCC range is large enough to carry all containers at one call per week. Interest was put towards small scale operations. Therefore, vessels that are larger than the SCCC are not of interest. In addition, waterway limitations for the Dortmund-Ems Canal (DEC) exclude the possibility to operate CEMT Va barges or vessels with more than three layers. Air draught for the DEC is 5.25 m and will not change soon because new bridges have been built at this height. However, the sluice chamber length at Münster has been enlarged to allow CEMT IV of up to 105 m in length [WSV, 2018].

The largest vessel available is therefore the 3313 type, which can carry 117 TEU at 100% loading condition. Loading this vessel according to the average container distribution leads to the result depicted in figure 10.2. The average loading container distribution was found to be 35%/60%/5% for 20/40/45 ft containers. All the 45ft containers are HC. The 40 ft is 25% standard height and 75% HC.

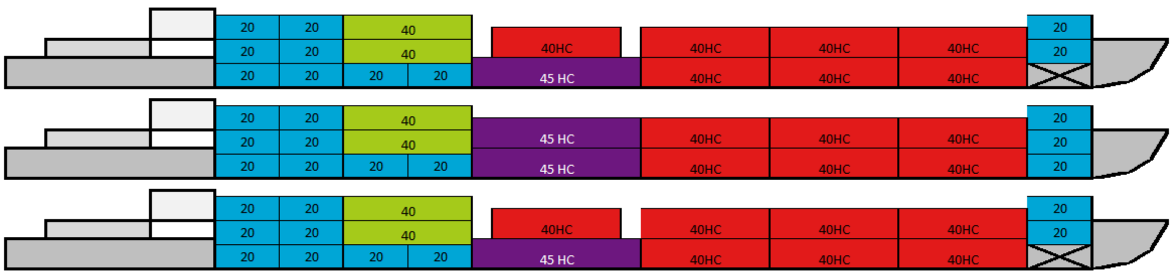


Figure 10.2: Portside, midship and starboard load overview when the default loading shares are applied.

If the standard distribution were adhered to, insufficient loading would occur due to the number of HC containers. These boxes can be loaded at the cost of a third layer, effectively reducing the sailed volume. The air draught limitation of the Dortmund-Ems Canal thus severely limits the loading capacity. The number of TEU-equivalent units loaded in the example of figure 10.2 is 91 TEU. In total, however, the example carries 61 boxes.

Pursuing loading conditions adhering the default loading shares will result in the long 3313. All this size is needed to accommodate all the HC containers. This large vessel will however have relatively high costs as it is only partially loaded.

A potential solution to this decreased capacity could be to increase the costs per HC container. For example, a 40"HC would be charged 1.5 times the cost of a standard 40" container. The resulting costs will be high due to the use of TEU-equivalent pricing in inland shipping. Competition on the Rhine does not include a HC charge. Were the SCCC to set this additional charge, it will lose part, if not all, of its competitive edge. Table 10.3 illustrates that the difference between a TEU-transported container with either the CEMT Va or Truck alternative is substantially bigger than for the other container dimensions. This is the result of the double cost allocation in the IWT transport part. The cost comparison later in this chapter will demonstrate whether such a HC charge could be installed and how this will affect the competitiveness of the SCCC operation.

Table 10.3: Out-of-pocket cost for competition

(a) CEMT Va competition

Sailing distance		200km		400km	
Container Type		20"	40" 40" HC 45" HC	20"	40" 40" HC 45" HC
PPH distance	50km	€369.44	€461.75	€415.59	€554.05
	100km	€506.31	€598.62	€552.46	€690.92
	150km	€669.94	€762.25	€716.09	€854.55

(b) Truck competition

Haulage distance	All box sizes
100km	€380.75
200km	€616.65
300km	€896.10
400km	€1,146.68

In case less HCs are carried, the loading of figure 10.3 would be more realistic. This would mean that at best, 103 TEU of 70 boxes can be carried (20/40/40HC/45HC = 37/21/9/3) at a loading degree of 88%. The TEU:FEU ratio than has come down to 1.5, when the default was 1.67. 18,000 TEU than translates to 12,000 boxes per annum. The last two columns of table 10.2 depict the effect on the number of boxes. A reduction of the box factor from 1.67 to 1.5 leads to an increase of 1,200 boxes at full capacity. When two 3313s are operated, their average loading degree becomes 76.9% with an upper loading limit of 88%.

Although the case proposes growth to 18,000 TEU at two calls per week, the first years will see partial throughput. It is therefore proposed to start with 1 SCCC for year 1, and when volumes keep increasing, offer a second SCCC and the second call per week. Investment costs are €3,653,000 per vessel (€2,910,000 for the hull and €743,000 for the HCGC aboard) for SCCC 3313 type. Because handling times are dependent on the loading degree, the SCCC is not capable of making two calls per week at full load conditions when adhering to the sailing regimen B. A fully loaded 3313 type will have a roundtrip time of just under 5 days.

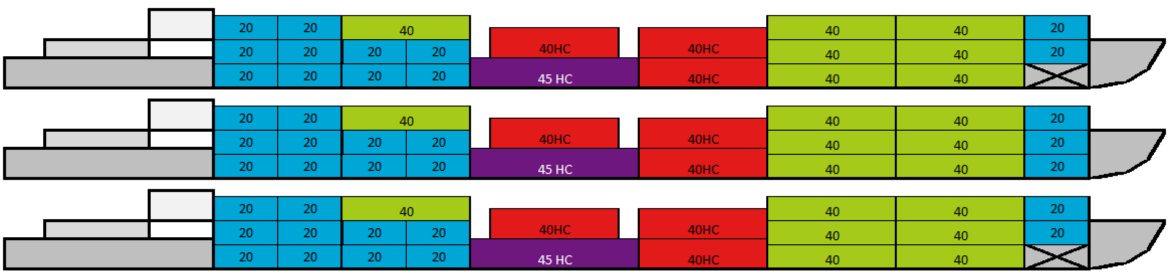


Figure 10.3: Portside, midship and starboard load overview at more realistic loading condition.

The SCCC 3313 type is currently selected but its precise cargo is unknown. If the standard loading allocation is followed, the vessel can accommodate 61 boxes, or 91 TEU. At modified loading shares, the carrying capacity increases to 70 boxes, or 103 TEU.

10.1.4. Best Fitting SCHC

At 9,000 TEU (5,400 boxes with TEU:FEU = 1.67) for the first year in which one ship is used, the required terminal capacity is 70 slots. In case the TEU:FEU is 1.5, 600 additional boxes will require handling. This requires an additional seven slots of capacity. Both these capacities are under the assumptions of limited direct throughput. With the call frequency of once per week, the storage of limited time will be the result because not all containers arrive at the IT when the client also demands its container.

Full capacity (18,000 TEU) at two calls per week requires either 81 slots (TEU:FEU = 1.67) or 90 slots (TEU:FEU = 1.5 slots) when no additional throughput is promoted. At 20% increased direct throughput, the capacity requirements decline by 20%, which results in 67 slots and 75 slots respectively. When throughput stays the same, additional investments are required after the first year because an additional number of slots is required.

At an application of this size, the scalability of the terminal can be used when building the initial layout. During the subsequent year, the scalability is most likely not required because the expected direct throughput share will increase. At the same time, a certain pricing strategy can lower storage demand and increase direct retrieval and delivery.

If the investor wants to build a terminal for a future throughput volume that is 50% larger, no larger vessel can be used. This will result in more calls and in this case leads to a third call during the week. At three calls per week and 16,200/18,000 boxes per year, the required capacity increases to between 100 and 120 slots. Depending on the certainty of the forecast and the aggressive market penetration strategy by the investor, the terminal may best be built for the original lay-out, as discussed at the end of Section 9.4. To recap, this is a two-alley, 20 slots per layer, three-layered design that can accommodate 120 box slots.
The original terminal capacity requirement is 70 to 77 slots in the first year and up to 75 slots in the second year, with increased direct throughput. If the terminal design of 9.4 is followed, this would mean that terminal is operated with two alleys of two layers. The layer size is 20 box slots, so the terminal will accommodate 80 slots altogether.

Table 10.4: Investment

Beginning of year	Required capacity	Required equipment investment
1	Two alley's, both two layers	€3,360,000
2	-	-
3	-	-
Possible future	Third layer on both alley's	€440,000

The results on page 152 (Tables 9.9 and 9.10) demonstrate that for an 80-box slot terminal and one call per week, the sustainable costs are €193.57 at a 6% discount rate. The same terminal at two calls per week and 20% increased direct throughput has costs lowered to €93.90.

The single call terminal has costs that are very high compared to currently-accepted levels in the industry. However, the fully-operating terminal that receives two calls per week has costs per box that are already lower than a current small-scale inland terminal. The small scale terminal's cost level was found in Chapter 5 to be €117 per box. It even approaches the market accepted average of €83.33.

The growth of the terminal is very important. The potential growth of 50% in a future year would lower the costs to €70 per box. These costs are below current market value and would be very rewarding to achieve.

10.2. Case Results

The lowest SCCC and SCHC cost levels for a 15-year investment are found when the net present value is equal to zero. In that case, no profit is made and no loss in incurred. To calculate these cost levels, several assumptions have been made based on what has been learned so far. Table 10.5 illustrates these assumptions. The residual values are set lower than normally true. Together with a short depreciation period, the depreciation in the first years is relatively high. The depreciation is used to lower the earning before interest and taxes (EBIT) in an effort to minimize the amount of taxes due.

Under the assumptions listed in Table 10.5, the minimum sustainable handling cost is €106. The sailing costs are €136 per TEU. If these costs are combined with the PPH costs (all out-of-pocket) from Section 9.2, the costs for transport of TEU, FEU, and high-cube containers to Münster, Osnabrück, and Bielefeld are found. Table 10.6 lists the resulting values. Remember that handling is equal for all boxes. Pre-haulage and post-haulage are only dependent on distance, not on the container it carries. The sailing costs result from the amount of TEUs the container requires. As previously stated, high-cube containers require triple cost allocations because they limit the vessel's carrying capacity.

Table 10.5: Assumptions for minimum cost level calculations

Factor		Terminal	First Vessel	Second Vessel
	Equipment	€3,360,000	€2,910,000	€2,910,000
	Other (land/crane)	€685,000	€743,000	€743,000
Total investment		€4,045,000	€3,653,000	€3,653,000
Residual value	Equipment	20%	30%	30%
Residual value	Other	20%	0%	0%
Bank loan		60% repaid in 15 years		60% in 14 years
Equity		40% kept in company		
Bank loan interest		6%		
Equity interest		0% since kept in company		
Depreciation time		10 years		9 years

Table 10.6: Resulting out-of-pocket cost for the concept tandem.

Container type	Destination	Distance from terminal	OOP Cost Sailing	Handling	PPH	Sum
TEU	Osnabrück (c)	30km	€136.00	€106.00	€152.00	€394.00
	Münster (c)	30km			€152.00	€394.00
	Bielefeld (c)	70km			€242.50	€484.50
FEU	Osnabrück (c)	30km	€272.00	€106.00	€152.00	€530.00
	Münster (c)	30km			€152.00	€530.00
	Bielefeld (c)	70km			€242.50	€620.50
40HC 45HC	Osnabrück (c)	30km	€408.00	€106.00	€152.00	€666.00
	Münster (c)	30km			€152.00	€666.00
	Bielefeld (c)	70km			€242.50	€756.50

Comparing these out-of-pocket costs listed in Table 10.7 does directly reveal opportunities. Beginning with the TEU costs, is it apparent that a TEU to Osnabrück (via Hengelo) is €136 more expensive (€530 vs. €394). A TEU to Münster is also cheapest via Hengelo, but €66 more expensive than the SCCC and SCHC can offer (€460 vs. €394). Bielefeld can be reached at the lowest cost via Dortmund at €125.5 more than the concepts' cost (€610 vs. €484.50).

The concept tandem is therefore feasible for the TEU market. Osnabrück allows a margin of at least €136, Münster €66 and Bielefeld €125.50. The CEMT Va costs were used for the Dortmund case, while in reality such a vessel cannot currently reach Dortmund. This means that additional costs will be generated, since a smaller vessel will lead to fewer EoS. In practice, the costs via Dortmund are assumed to be 10% higher. This effect is already incorporated in the results ((c) = center, (r) = region).

If the same comparison is made for FEUs, the results are slightly different. An FEU can be most inexpensively transported to Osnabrück via Hengelo at €620, while the concept tandem requires at least €530. The SCCC and SCHC tandem therefore has costs €90 lower than their competition. Münster is also best reached via Hengelo for as little as €550, which is €20 more than the concepts' cost level (€530). Transport to Bielefeld is €720 via Dortmund and therefore costs €99.50 more than the concepts (€620.50). As with TEU transport, the concepts can transport FEUs for less than the existing competition can.

Whereas cost comparisons for TEU and FEU transport turned out to be in favor of the SCCC and SCHC tandem, this favorable cost level is not true for high-cube boxes that are triple charged. In all three cases, the out-of-pocket costs for the SCCC and SCHC tandem are higher than those for the current competition. This can be explained by the fact that for the FEU transport margins found are smaller than the sailing cost of an additional TEU. The 40" HCs and 45" HCs, however, are charged for one additional TEU during the sailing leg of the transport chain, the result being that the concept cannot offer a competitive rate when this true cost allocation is appointed.

Looking at the difference for the HC transport as an example it is also apparent that, for instance, containers between Bielefeld and Rotterdam can be transported via four different existing terminals and via truck. The concept cost level is below that of truck (€1,120 vs. €756.50), below that of (CTT) Hengelo (€790 vs. €756.50), below that of (Duisport) Duisburg (€830 vs. €756.50), and below that of Wesel (€810 vs. €756.50). Clients that currently transport their HC containers via these options will therefore realize that the SCCC and SCHC tandem can offer a reduction in transport costs

Table 10.8 lists the cost savings of using the SCCC and SCHC tandem instead of an existing option. For TEUs and FEUs, the concept is always the least expensive option. For HCs, the costs of the concept tandem are lower compared to truck haulage. Compared to 12 competing options, the concept is more expensive in 50% of the cases and cheaper in the other 50%. Overall, for three container sizes, 15 options are available per size. For the sum of 45 transport chains, the concept can offer transport at lower out-of-pocket costs in 39 of the 45 cases.

When the default container share (35/15/45/5 for 20/40/40HC/45HC) is applied to this case, the annual container throughput assumption can be verified in the most basic way possible. Imagine a case in which 45,000 boxes (75,000 TEUs) are being transported in the Münster/Osnabrück/Bielefeld region. These can all potentially be attracted for a mode shift and are all equally distributed over the 45 transport options following the default share.

The concept is the lower cost alternative for all TEUs transported (15 out of 45), and this represents 35% of the annual share. The same lower costs are achieved for standard height FEU containers, attracting another 15 out of 45 and representing 15%. Of the 40" HC, nine out of 15 can be attracted at a 45% annual share. For the 45" HC containers, the same nine out of 15 options are cheaper at a 5% share. Altogether, 36,000 boxes could be attracted based on out-of-pocket costs alone. This suggests that the assumed 12,000 boxes were a very safe estimate. Altering the default share to the share as described in Subsection 10.1.3, 41,000 boxes could potentially be attracted.

Table 10.7: Out-of-pocket cost for truck and IWT competition when using existing options.

Mode	Origin	Destination	Hub	Distance	GC (excl. EC) TEU	FEU	Box
Truck	Hutchinson ECT Delta	Osnabrück (c)	-	330km		€970	
		Münster (c)	-	300km		€900	
		Bielefeld (c)	-	390km		€1120	
CEMT Va	Hutchinson ECT Delta	Osnabrück (c)	CTT Hengelo	260 + 105km	€530	€620	€590
		Münster (c)		260 + 80km	€460	€550	€520
		Bielefeld (c)		260 + 160km	€700	€790	€760
		Osnabrück (c)	Duisport 3T	250 + 160km	€690	€790	€760
		Münster (c)		250 + 110km	€540	€640	€600
		Bielefeld (c)		250 + 180km	€740	€830	€800
		Osnabrück (c)	Dortmund CT (+10%)	310 + 120km	€640	€760	€720
		Münster (c)		310 + 70km	€480	€600	€560
		Bielefeld (c)		310 + 110km	€610	€720	€680
		Osnabrück (c)	Wesel	230 + 165km	€700	€790	€760
		Münster (c)		230 + 115km	€550	€640	€610
		Bielefeld (c)		230 + 175km	€720	€810	€780

Table 10.8: Out-of-pocket cost saving when using SCCC and SCHC tandem instead of existing options.

Mode	Origin	Destination	Hub	Distance	GC (excl. EC) TEU	FEU	HCs
Truck	Hutchinson ECT Delta	Osnabrück (c)	-	330km	€567.00	€440.00	€304.00
		Münster (c)	-	300km	€506.00	€370.00	€234.00
		Bielefeld (c)	-	390km	€635.50	€499.50	€363.50
CEMT Va	Hutchinson ECT Delta	Osnabrück (c)	CTT Hengelo	260 + 105km	€136.00	€90.00	(€46.00)
		Münster (c)		260 + 80km	€66.00	€20.00	(€116.00)
		Bielefeld (c)		260 + 160km	€215.50	€169.50	€33.50
		Osnabrück (c)	Duisport 3T	250 + 160km	€296.00	€260.00	€124.00
		Münster (c)		250 + 110km	€146.00	€110.00	(€26.00)
		Bielefeld (c)		250 + 180km	€255.50	€209.50	€73.50
		Osnabrück (c)	Dortmund CT (+10%)	310 + 120km	€246.00	€230.00	€94.00
		Münster (c)		310 + 70km	€86.00	€70.00	(€66.00)
		Bielefeld (c)		310 + 110km	€125.50	€99.50	(€36.50)
		Osnabrück (c)	Wesel	230 + 165km	€306.00	€260.00	€124.00
		Münster (c)		230 + 115km	€156.00	€110.00	(€26.00)
		Bielefeld (c)		230 + 175km	€235.50	€189.50	€53.50

The comparison between the concept and competition does not end with a comparison of the out-of-pocket cost. On the contrary, the out-of-pocket cost comparison could be considered a measure for those not overseeing the bigger transport picture. When the time cost and risk & reliability of the transport option are incorporated, a significantly more realistic transport cost comparison can be made. A transport manager seeking the transport option that is truly the most efficient in terms of cost will look at the generalized costs. The marginal willingness-to-pay (WTP) for external damages resulting from transport make that most transporters do not currently include this in their considerations. The resulting costs are calculated and listed in Table 10.9.

Table 10.11 indicates the resulting potential savings. Including time cost and risk & reliability has decreased the potential saving. This time the transport of a FEU to Münster (via Hengelo) is less expensive when using the competition rather than the concept tandem. The overall effect is makes sense because the current market alternatives offer higher frequency sailing, and the sailing distances are shorter. Sailing is slow and therefore time-consuming, leading to higher time costs. The result is therefore that the concept tandem performance is less favorable when incorporating the time and risk & reliability.

For the FEUs and HCs, the negative differences are minimal in several cases. The superior concepts' container retrieval and deposit options on the landside transfer side are not incorporated in these numbers. In reality, however, it would be reasonable if the transport manager also included this in his/her consideration. The unmanned terminal allows for 24/7 operations without breaks. This superior interactivity between terminal and truck operations will make up for the small negative generalized cost when the external costs are excluded. Many HCs are substantially more expensive, which again is the result of the triple cost allocation.

When the external costs are also included, as depicted by table 10.13, the results improve in favour of the SCCC and SCHC tandem. Penetrating the capillaries of the network leads to a more rural location for the terminal. The PPH distances between the cities and the concept terminal in Ladbergen are far less than between the cities and the existing terminals, the result being that the sailing share in the entire transport chain is maximized and the resulting PPH is minimized. Only for the high-cube containers one transport case, Münster via Hengelo, remains at a deficit. This is again caused by the triple TEU allocation, which also applies to the external costs. As previously explained, the vessel's total external effect is monetized. Since the HC containers take up more height, they require triple cost allocation in order to determine the break-even cost.

It is therefore apparent that when the default loading share is adhered to , the concept can achieve lower costs for a TEU transported to any of the three cities in terms of out-of-pocket costs, generalized cost excluding EC, and generalized cost including EC. Compared to the competition, the concepts can offer transport of an FEU at lower out-of-pocket costs for all cities. Including time and risk & reliability leads to lower margins. Transport to Münster via both Hengelo and Dortmund becomes problematic in terms of cost comparison, but including the external costs renders all generalized costs positive.

Due to the air draught limitations on the Dortmund-Ems Canal, HCs limit the loading degree. Including an additional charge immediately leads to multiple cases in which the concept tandem is (significantly) more expensive for both out-of-pocket. Comparing the generalized costs (excl. EC) even leads to higher costs for all shipping cases. Again, including external costs is beneficial for the SCCC and SCHC tandem. What remains is the single case in which the tandem has higher costs.

Tables 10.8, 10.11 and 10.13 all three indicate a strong potential saving when using the SCCC and SCHC instead of long-distance truck haulage. It can thus be concluded that, even with this cost allocation, the concepts offer a beneficial alternative. For the transport planner that is currently using truck haulage might be pursued with these very high potential savings in sight.

Table 10.9: Resulting generalised cost for the concept tandem.

Container Type	Destination	Distance to Terminal	OOP	GC factors Time	R&R	EC	GC (excl. EC)	GC (incl. EC)
TEU	Osnabrück (c)	30km	€394.00	€55.00	€29.00	€175.50	€478.00	€653.50
	Münster (c)	30km	€394.00			€175.50	€478.00	€653.50
	Bielefeld (c)	70km	€484.50			€340.50	€568.50	€909.00
FEU	Osnabrück (c)	30km	€530.00	€110.00	€58.00	€204.50	€698.00	€902.50
	Münster (c)	30km	€530.00			€204.50	€698.00	€902.50
	Bielefeld (c)	70km	€620.50			€370.50	€788.50	€1159.00
40HC 45HC	Osnabrück (c)	30km	€666.00	€165.00	€87.00	€228.50	€918.00	€1146.50
	Münster (c)	30km	€666.00			€228.50	€918.00	€1146.50
	Bielefeld (c)	70km	€756.50			€394.50	€1008.50	€1403.00

Table 10.10: Generalised cost (excl. EC) for truck and IWT competition when using existing options.

Mode	Origin	Destination	Hub	Distance	GC (excl. EC) TEU	FEU	Box
Truck	Hutchinson ECT Delta	Osnabrück (c)	-	330km	€1010	€1020	
		Münster (c)	-	300km	€930	€940	
		Bielefeld (c)	-	390km	€1160	€1170	
CEMT Va	Hutchinson ECT Delta	Osnabrück (c)	CTT Hengelo	260 + 105km	€590	€750	€690
		Münster (c)		260 + 80km	€520	€680	€620
		Bielefeld (c)		260 + 160km	€760	€920	€860
		Osnabrück (c)	Duisport 3T	250 + 160km	€760	€910	€860
		Münster (c)		250 + 110km	€600	€760	€700
		Bielefeld (c)		250 + 180km	€800	€960	€900
		Osnabrück (c)	Dortmund CT (+10%)	310 + 120km	€720	€910	€850
		Münster (c)		310 + 70km	€560	€750	€690
		Bielefeld (c)		310 + 110km	€680	€870	€810
		Osnabrück (c)	Wesel	230 + 165km	€760	€910	€860
		Münster (c)		230 + 115km	€610	€760	€710
		Bielefeld (c)		230 + 175km	€780	€930	€880

Table 10.11: Generalised (excl. EC) cost saving when using SCCC + SCHC tandem instead of using existing options.

Mode	Origin	Destination	Hub	Distance	GC (excl. EC) TEU	FEU	HC's
Truck	Hutchinson ECT Delta	Osnabrück (c)	-	330km	€532.00	€322.00	€102.00
		Münster (c)	-	300km	€452.00	€242.00	€22.00
		Bielefeld (c)	-	390km	€591.50	€381.50	€161.50
CEMT Va	Hutchinson ECT Delta	Osnabrück (c)	CTT Hengelo	260 + 105km	€112.00	€52.00	(€168.00)
		Münster (c)		260 + 80km	€42.00	(€18.00)	(€238.00)
		Bielefeld (c)		260 + 160km	€191.50	€131.50	(€88.50)
		Osnabrück (c)	Duisport 3T	(250 + 160km	€282.00	€212.00	(€8.00)
		Münster (c)		250 + 110km	€122.00	€62.00	(€158.00)
		Bielefeld (c)		250 + 180km	€231.50	€171.50	(€48.50)
		Osnabrück (c)	Dortmund CT (+10%)	310 + 120km	€242.00	€212.00	(€8.00)
		Münster (c)		310 + 70km	€82.00	€52.00	(€168.00)
		Bielefeld (c)		310 + 110km	€111.50	€81.50	(€138.50)
		Osnabrück (c)	Wesel	230 + 165km	€282.00	€212.00	(€8.00)
		Münster (c)		230 + 115km	€132.00	€62.00	(€158.00)
		Bielefeld (c)		230 + 175km	€211.50	€141.50	(€78.50)

Table 10.12: Generalised cost (incl. EC) for truck and IWT competition when using existing options.

Mode	Origin	Destination	Hub	Distance	GC (excl. EC) TEU	FEU	Box
Truck	Hutchinson ECT Delta	Osnabrück (c)	-	330km	€2210	€2220	
		Münster (c)	-	300km	€2030	€2040	
		Bielefeld (c)	-	390km	€2560	€2570	
CEMT Va	Hutchinson ECT Delta	Osnabrück (c)	CTT Hengelo	260 + 105km	€1040	€1220	€1160
		Münster (c)		260 + 80km	€890	€1070	€1000
		Bielefeld (c)		260 + 160km	€1400	€1580	€1520
		Osnabrück (c)	Duisport 3T	250 + 160km	€1400	€1580	€1510
		Münster (c)		250 + 110km	€1070	€1250	€1190
		Bielefeld (c)		250 + 180km	€1510	€1690	€1630
		Osnabrück (c)	Dortmund CT (+10%)	310 + 120km	€1280	€1500	€1420
		Münster (c)		310 + 70km	€930	€1150	€1070
		Bielefeld (c)		310 + 110km	€1200	€1420	€1350
		Osnabrück (c)	Wesel	230 + 165km	€1420	€1590	€1530
		Münster (c)		230 + 115km	€1100	€1270	€1210
		Bielefeld (c)		230 + 175km	€1470	€1650	€1590

Table 10.13: Generalised (incl. EC) cost savings for truck and IWT competition when using existing options.

Mode	Origin	Destination	Hub	Distance	GC (excl. EC) TEU	FEU	HC's
Truck	Hutchinson ECT Delta	Osnabrück (c)	-	330km	€1556.50	€1317.50	€1073.50
		Münster (c)	-	300km	€1376.50	€1137.50	€893.50
		Bielefeld (c)	-	390km	€1651.00	€1411.00	€1167.00
CEMT Va	Hutchinson ECT Delta	Osnabrück (c)	CTT Hengelo	260 + 105km	€386.50	€317.50	€73.50
		Münster (c)		260 + 80km	€236.50	€167.50	(€76.50)
		Bielefeld (c)		260 + 160km	€490.00	€421.00	€177.00
		Osnabrück (c)	Duisport 3T	250 + 160km	€746.50	€677.50	€433.50
		Münster (c)		250 + 110km	€416.50	€647.50	€103.50
		Bielefeld (c)		250 + 180km	€601.00	€531.00	€287.00
		Osnabrück (c)	Dortmund CT (+10%)	310 + 120km	€626.50	€597.50	€353.50
		Münster (c)		310 + 70km	€276.50	€247.50	€3.50
		Bielefeld (c)		310 + 110km	€291.00	€261.00	€17.00
		Osnabrück (c)	Wesel	230 + 165km	€766.50	€687.50	€443.50
		Münster (c)		230 + 115km	€446.50	€367.50	€123.50
		Bielefeld (c)		230 + 175km	€561.00	€491.00	€247.00

The results indicate sufficient feasibility for TEU and FEU containers. The cost level of HC container transport by the SCCC and SCHC tandem means that only containers in a few situation will be attracted. Based on the generalized costs (excluding EC; see Table 10.11) cost savings, only HC containers currently transported by truck will be better off when using the concept tandem. In all other cases, they would be better off using existing solutions. Reflecting back on the assumptions made regarding containers in Figure 10.3, it is apparent that such a loading scheme would be much more realistic.

Now results have shown preliminary feasibility it is proposed to discuss the modified loading conditions results. The *'3313'* depicted in Figure 10.3, at modified share, is loaded with 115 equivalent units (70 boxes). At two vessels and 50 roundtrip per year the total sailed volume would add up to 14,000 boxes (23,000 TEU). This is more than what was predetermined to be the case limit. By result, the vessel will not require full loading in those loading conditions to transport 18,000 TEU (12,000 boxes) per year. This would leave opportunities for future growth of 2,000 boxes per year.

If the vessel's loading is limited to the predetermined limit, it carries a maximum of 90 TEUs (61 boxes). Figure 10.4 depicts the proposed realistic loading. The vessel carries 34 TEU containers, 15 FEU containers, six FEU HCs, and six 45-foot HC containers. 45" HC containers are counted as 2.25 TEUs according to the industry standard.

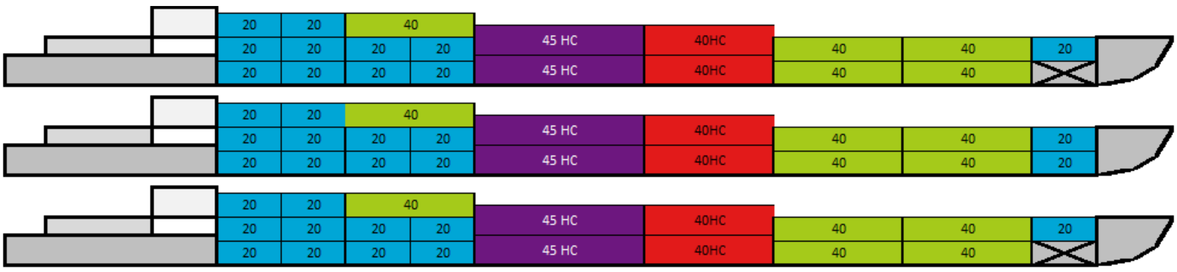


Figure 10.4: Portside, midship and starboard load overview at presumed sailed loading condition.

Translating this loading degree to TEU charged equivalent units, it could be decided to charge three equivalent units for the HCs. Following this counting method, however, the total load is 100 TEUs, which would reduce the effective price per TEU. Since the TEU boxes are already substantially less expensive than those of the competition, a different pricing strategy is proposed. The HCs are counted as 2.25 TEUs instead of 3 TEUs, the result being that 91 TEU equivalents can be shipped at once. Over the course of a year, this adds up to 18,200 TEU counting units (12,200 boxes).

The result of this improved calculation method is a decrease in costs for out-of-pocket and both generalized cost expenses. The cost difference between the concepts and the competition is largest for the TEU containers. By the lower charge on HC containers, their out-of-pocket costs have declined significantly (€115). High-cube containers can therefore now also be shipped at the lowest cost via the concept.

Operating at the minimum cost level means that at a 6% discount rate the NPV is zero. The project IRR is therefore 6%, and the IRR on equity is 14.6%. Figure 10.5 contains the resulting financial graphs, which indicate that cash flow is negative for the first three years and afterwards remains positive. Throughout the duration of the project, the results (net result) are added to the equity and liquid assets. This demonstrates that cash flow is negative for the first three years, which could cause problems. The equity of the owner, however, can act as a buffer for work credit financing. Since the company does not make a profit, the resulting free cash flow after 15 years is zero.

When the found margins are used to operate above cost levels, however, a profit can be made. Operating a handling tariff per box of €105 and a sailing cost of €150 per TEU, the NPV becomes €4,044,939, the project IRR becomes 8.9%, and the equity IRR becomes 18.7%. The resulting financial graphs are provided in Figure 10.6. In this case, the company is making an overall profit that reflects the positive discounted cumulative cash flow after Year 15. Again, without dividend payments to the private investor, the equity and liquid assets grow. This time, they both increase very rapidly. As the cumulative cash flow in the upper right corner indicates, private investors will have to wait 15 years to get their high initial investments back. Leaving this earned capital in the existing business is not, however, what one should pursue. New business opportunities might be looming, and with the money stuck in the company, these are not directly pursued.

Paying a dividend is not free. A dividend tax rate of 15% is adopted. A dividend withdrawal of €100,000, for example, will cost €115,000 since the dividend tax has to be paid. During the first three years, cash flows are not at their maximum level because the shipped volumes are still increasing. From Year 4 onwards, the liquid assets recover and strong results are achieved. Withdrawing €300,000 from the terminal and €250,000 from each vessel per year increases the cash flow in earlier years and lowers the final payment after 15 years. Figure 10.7 demonstrates how the payback period for the entire project comes forward a little bit. Both equity and liquid asset growth is reduced substantially.

In this case, the NPV becomes €4,070,274 at a 6% discount value. Project IRR is 9.4% and equity IRR is 21%. With an equity investment of €4,540,400 and annual dividend payments of €800,000 from Year 4 onwards, the payback period on equity is less than 6 years. This means that during the ninth year of operation the private investor has regained his/her initial cash investment. The dividend is not indexed for inflation to keep calculations simple, and since none of the costs and revenues are indexed to match inflation, this is mostly correct.

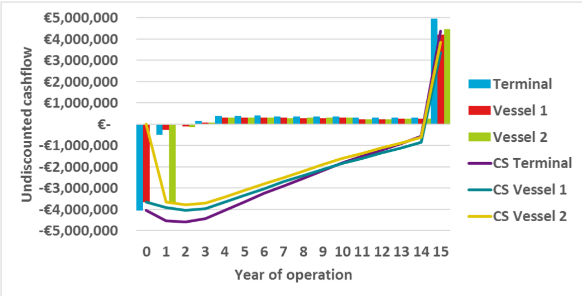
Financial benefits or setbacks due to different market values of the residual terminal and/or vessel are left out for the time being in case the terminal is sold to or valued higher than the book value, after 15 years, additional income is received. The reverse also applies. If the market for container transport, container vessels, and/or terminals is worse than the forecast, the residual value will fall short of expectations. Such an effect will reduce the final result and can even result in a negative final result. Overestimating residual value is therefore a sensitive case with potentially large effects. To give an example, the used vessel is written off at 30% of the original value. If the vessel turns out to be worthless, only 5% of the vessel's initial value may be left as scrap value. A setback of 25% of €727,500 is incurred at that time.

Table 10.14: Resulting out-of-pocket cost for the concept tandem at real operation.

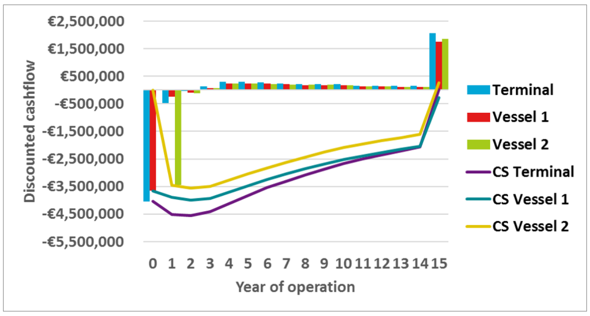
Container type	Destination	Distance from terminal	OOP Cost Sailing	Handling	PPH	Sum
TEU	Osnabrück (c)	30km	€134.50	€96.00	€152.00	€382.50
	Münster (c)	30km			€152.00	€382.50
	Bielefeld (c)	70km			€242.50	€473.00
FEU	Osnabrück (c)	30km	€269.00	€96.00	€152.00	€517.00
	Münster (c)	30km			€152.00	€517.00
	Bielefeld (c)	70km			€242.50	€607.50
40HC 45HC	Osnabrück (c)	30km	€303.00	€96.00	€152.00	€551.00
	Münster (c)	30km			€152.00	€551.00
	Bielefeld (c)	70km			€242.50	€641.50

Table 10.15: Resulting generalized cost for the concept tandem at real operation.

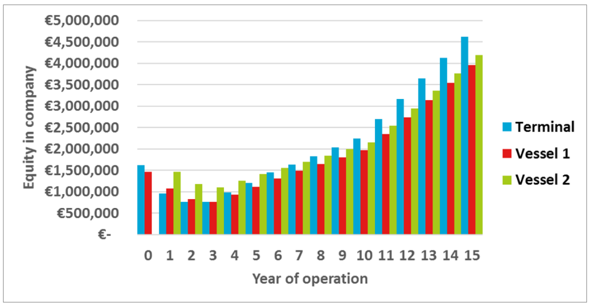
Container type	Destination	Distance to terminal	OOP	GC factors Time	R&R	EC	GC (excl. EC)	GC (incl. EC)
TEU	Osnabrück (c)	30km	€382.50	€55.00	€29.00	€175.50	€466.50	€642.00
	Münster (c)	30km	€382.50			€175.50	€466.50	€642.00
	Bielefeld (c)	70km	€473.00			€341.00	€557.00	€898.00
FEU	Osnabrück (c)	30km	€517.00	€110.00	€58.00	€204.50	€685.50	€889.50
	Münster (c)	30km	€517.00			€204.50	€685.50	€889.50
	Bielefeld (c)	70km	€607.50			€370.50	€775.50	€1146.00
40HC 45HC	Osnabrück (c)	30km	€551.00	€124.00	€65.50	€228.50	€740.50	€969.00
	Münster (c)	30km	€551.00			€228.50	€740.50	€969.00
	Bielefeld (c)	70km	€641.50			€394.50	€831.00	€1225.50



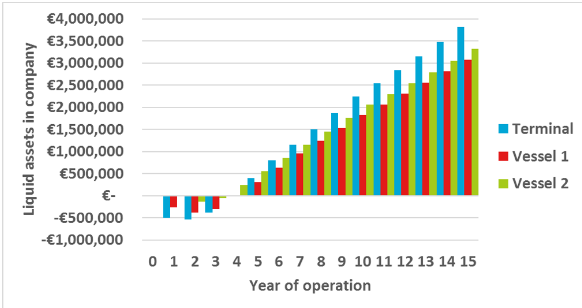
(a) Un-discounted cash flow.



(b) Discounted cash flow.

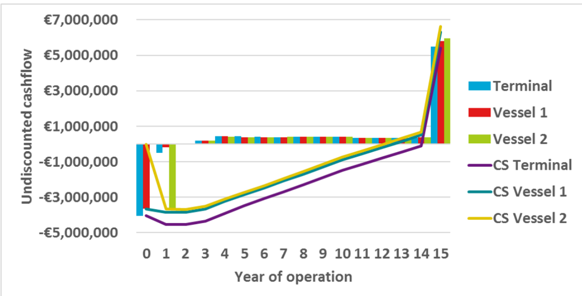


(c) Equity development over time.

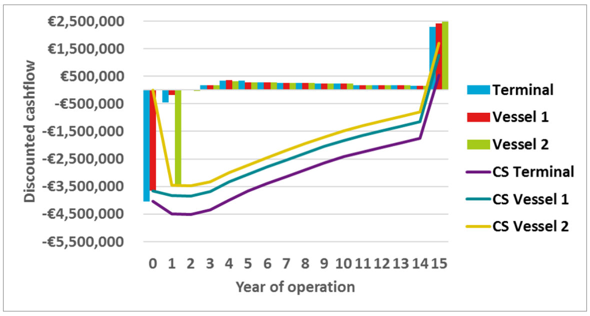


(d) Liquid assets development over time.

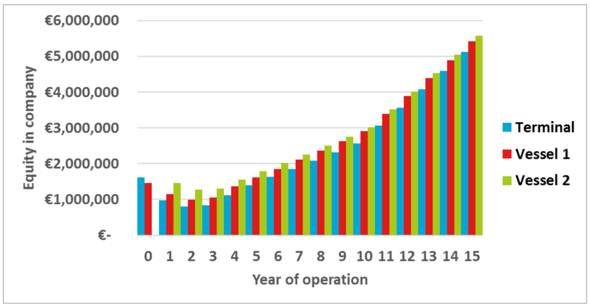
Figure 10.5: Financial results at cost level operation, no dividend payments and 6 percent discounting.



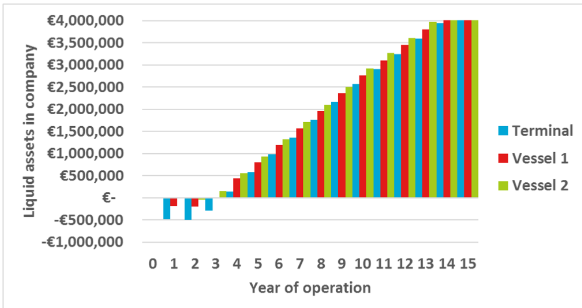
(a) Un-discounted cash flow.



(b) Discounted cash flow.

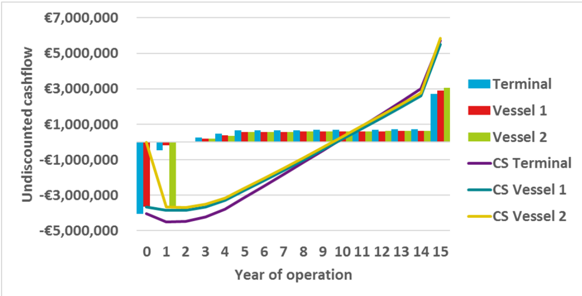


(c) Equity development over time.

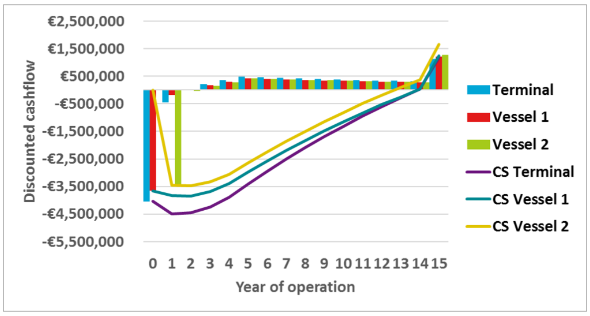


(d) Liquid assets development over time.

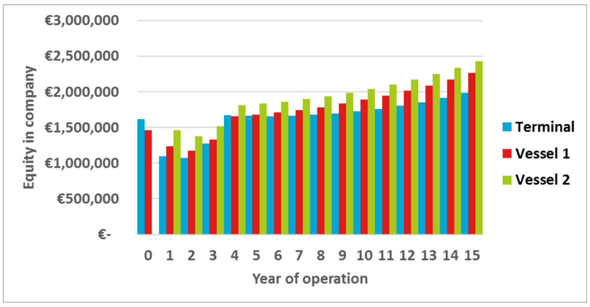
Figure 10.6: Financial results at competitive price operation, no dividend payments and 6 percent discounting.



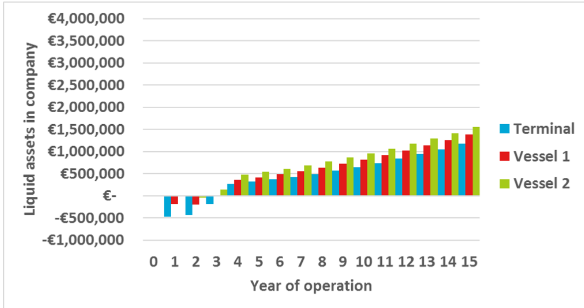
(a) Un-discounted cash flow.



(b) Discounted cash flow.

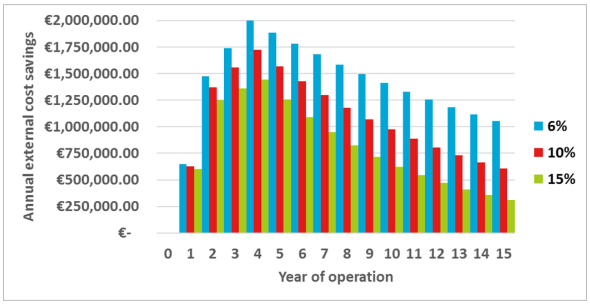


(c) Equity development over time.

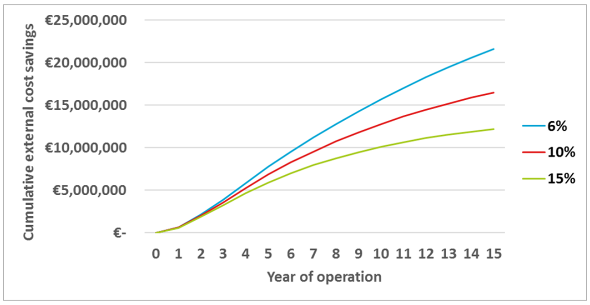


(d) Liquid assets development over time.

Figure 10.7: Financial results at competitive price operation, dividend payments from year 4 and 6 percent discounting.



(a) Annual external cost savings for three different discount rates.



(b) Cumulative external cost savings for three different discount rates.

Figure 10.8: Cost-Benefit results.

10.2.1. Price Setting and Attracting Containers

The previous calculations were for a fictive case in which the tariff was set slightly above the cost level. When the terminal and vessel investments are made and the company is ready to start business, it will most likely not communicate a fixed price per TEU. Why this is not done is explained in this subsection. Consider the case of a cargo owner that has a factory in Osnabrück. Based on the existing terminals and options under consideration, five options are available. Table 10.16 lists the three cost level considerations that can be consider. The additional costs for all of these options when compared to the cost level of the concept tandem are listed in parentheses. This indicates that the Hengelo option has the lowest costs for existing terminals. The minimum cost reduction the cargo owner can make (in case he/she is already shipping via Hengelo) is €123.50. As long as the tariff markup the SCCC and SCHC charge stays below this amount, the concept will be able to offer transport at lower costs. In this case, for example, the concept vessel and terminal together can earn €100 and still operate at a cost level below that of the best alternative. If the cargo owner is not currently using Hengelo because he/she is unsatisfied by the service, for instance, the markup the concept can realize is even larger.

Cargo owners' satisfaction with the current situation has not been incorporated into this study. If the concept were to offer a €10 discount when it first begins offering its services, for example, cargo owners might not change services. It could be that the current terminal offers good service that is deemed sufficient. Another possibility is that a truck also has other business in the area of that terminal and is going that direction anyway. Only revolutionary prices with very sharp rates can persuade cargo owners to reconsider.

Maybe even more important than price is the service offered. When the landside transfers are not going smoothly, the location is difficult to reach, the terminal faces many breakdowns, etc., the transport director will devalue the concepts offer. As the saying goes, "Trust takes years to build, seconds to break, and forever to fix," and this is also the case for concept terminal success. When goods do not arrive on time, the result might be significantly more expensive than any potential saving was worth.

Table 10.16: Price setting based on costs of competition for a TEU transported between Rotterdam and Osnabrück.

Mode	Inland Terminal	OOP	GC (excl.)	GC (incl.)
Truck	-	€970.00 (+€587.50)	€1010.00 (+€543.50)	€2210.00 (+€1568.00)
CEMT VA	CTT Hengelo	€530.00 (+€147.50)	€590.00 (+€123.50)	€1040.00 (+€398.00)
CEMT VA	Duisport 3T	€690.00 (+€307.50)	€760.00 (+€293.50)	€1400.00 (+€758.00)
CEMT VA	Dortmund CT	€640.00 (+€257.50)	€720.00 (+€253.50)	€1280.00 (+€638.00)
CEMT VA	Wesel	€700.00 (+€317.50)	€760.00 (+€293.50)	€1420.00 (+€778.00)
SCCC	SCHC Ladbergen	€382.50	€466.50	€642.00

Truck haulage also turned out to be far more expensive in all previous tables. Still, this mode is used very frequently and was even the reason for this thesis. The real reason behind this significant use lies in flexibility and in cargo owners who do not care. In many cases, the transport costs are very low compared to the contents of the container. For example, if a FEU full of sneakers is imported, it can contain as many as 10,000 pairs of shoes. This means that each €100 of additional transport cost increases the costs per pair by only €0.01. If these shoes are later sold for €50, these additional transport costs can be forgotten. On the upside, trucking offers quick delivery and flexibility and may even require less planning overall. It is therefore difficult to quantify upfront what kinds of cargo owners can be really persuaded to apply a mode shift to.

In contrast with already shipped goods, Figure 2.4 shows cargo with the potential to be transported. As previously explained, these goods may currently not be transported because the costs are too high. With the lower costs and thereby the lower tariff charged by the concepts, these cargo owners may reconsider their decision against shipping. At the same time, these lower transport costs will increase the competitive strength of all cargo owners in the service area.

10.2.2. Sensitivity of Feasibility

The previously discussed cost levels are the result of calculations based on default values resulting from earlier analysis in this thesis. The proposed case is favorable because it enables to operate in an efficient manner. The volumes are optimized for maximum utilization at a total annual volume ≤ 20,000 TEUs. It has been demonstrated that feasibility is possible for this case; however, what happens if circumstances differ from expectations? Changed input parameters automatically affect the resulting minimum sustainable cost level. Table 10.17 contains nine possible variations that could occur, and the previous subsection discussed the effects a subsidy could have. Minimum cost levels for this case are listed in Table 10.17b.

Assumed annual values were very carefully proposed based on references known in other terminal cases. It could occur, however, that the investor invests in the terminal and the two vessels and that due to changed market conditions, the annual volumes fall short of their forecast. When the volume falls short by 10%, Table 10.17c, costs increase to €105 (H[1] = €96) and €147.75 (S = €134.50). The costs for a TEU will then increase by €20, while costs for a FEU will increase by €35. At 20% reduced annual volumes, Table 10.17d, the costs increase to €115.50 (H = €96) and €162.75 (S = €134.50). Such an increase is really substantial and will have a far-reaching impact on operations. In this case, the transport cost for a FEU would increase by €80. Transport alternatives via Hengelo to Münster, for instance, will be lower cost alternatives. The attractiveness of the new service will therefore be severely limited in such a case. It is even possible that the increased cost will lead to a higher tariff for the concept terminal. This will reduce the attractiveness even further, which could cause a downward spiral.

Slightly increased volumes will reduce the cost per container. Figure 10.17e demonstrates this result. The lower costs due to growing volumes will mean more than business going good. It might be that the terminal and/or vessel operations could grow by additional investments. Lower costs mean higher margins and/or lower tariffs, which will further increase the profitability of operations. It does not necessarily have to mean that the same vessel will have to be bought again. The third ship could perhaps sail to Antwerp or Amsterdam, depending on demand. Another option would be inland shipping to Bremerhaven or Hamburg, if that were demanded and accessible by CEMT ≤ IV vessels.

Another primary influencing parameter is the financing aspect. A shorter lending period of 10 years rather than 15 increases costs, as indicated in Table 10.17f. The effect is in the order of a couple of euros and is therefore marginal in terms of the overall transport costs.

An effect of a similar size but with a positive impact on costs would be to decrease the bank loan share to 40% (the default is 60%). This lowers costs by a few euros. The effect of this lowered loan overcomes the shortened repayment period, as illustrated in Table 10.17g.

The logical third case is equity financing only. In this case, the costs are substantially below the default case. As previously indicated, however, negative operations will have to be incurred during the first years. To survive this period and not get into default means keeping sufficient equity as a buffer. This equity can then be used as working capital.

The interest level is of minimal impact, as illustrated in Tables 10.17i and 10.17j. One of the reasons for this is the accounting rules according to which interest may be subtracted from the result. Over the result after interest tax is due. Higher interest will reduce the result and thereby lower taxes. The overall impact of higher interest payments is therefore partially buffered down by this accounting effect, and the opposite is also true.

[1] H = Handling cost, S = Shipping cost per TEU

Table 10.17: Sensitivity results

(a) Minimum cost level base case.

Discount rate	Handling cost box	Shipping cost TEU
3%	€86.42	€124.17
4%	€89.46	€127.90
5%	€92.73	€131.58
6%	€96.24	€135.45
7%	€99.98	€139.55
8%	€103.96	€143.89

(b) Minimum cost level subsidised.

Discount rate	Handling cost box	Shipping cost TEU
3%	€82.38	€119.32
4%	€85.02	€122.23
5%	€88.09	€125.34
6%	€91.52	€128.75
7%	€94.88	€132.85
8%	€98.46	€136.82

(c) Minimum cost level 10% lower annual volume

Discount rate	Handling cost box	Shipping cost TEU
3%	€94.36	€135.52
4%	€97.71	€139.39
5%	€101.21	€143.60
6%	€104.95	€147.71
7%	€109.07	€152.07
8%	€113.35	€156.83

(d) Minimum cost level 20% lower annual volume

Discount rate	Handling cost box	Shipping cost TEU
3%	€103.75	€149.14
4%	€107.74	€153.23
5%	€111.53	€157.93
6%	€115.58	€162.62
7%	€119.90	€167.31
8%	€124.49	€172.25

(e) Minimum cost level 10% higher annual volume

Discount rate	Handling cost box	Shipping cost TEU
3%	€79.66	€114.63
4%	€82.51	€118.01
5%	€85.57	€121.42
6%	€88.86	€125.07
7%	€92.38	€128.94
8%	€96.12	€133.05

(f) Minimum cost level 10 year bank loan

Discount rate	Handling cost box	Shipping cost TEU
3%	€93.83	€128.14
4%	€96.83	€131.74
5%	€100.07	€135.77
6%	€103.54	€139.94
7%	€107.25	€144.20
8%	€111.20	€148.69

(g) Minimum cost level 40% bank loan in 10 years repaid.

Discount rate	Handling cost box	Shipping cost TEU
3%	€82.15	€116.47
4%	€85.05	€119.75
5%	€88.34	€123.25
6%	€91.94	€127.02
7%	€95.54	€131.36
8%	€99.39	€136.00

(h) Minimum cost level only equity financing

Discount rate	Handling cost box	Shipping cost TEU
3%	€60.86	€94.11
4%	€63.06	€96.74
5%	€65.94	€99.81
6%	€69.01	€103.24
7%	€72.28	€106.86
8%	€75.73	€110.68

(i) Minimum cost level at 8% interest rate.

Discount rate	Handling cost box	Shipping cost TEU
3%	€88.53	€127.04
4%	€91.52	€130.27
5%	€94.90	€133.72
6%	€98.58	€137.66
7%	€102.28	€142.02
8%	€106.22	€146.42

(j) Minimum cost level at 4% interest rate.

Discount rate	Handling cost box	Shipping cost TEU
3%	€83.59	€121.30
4%	€86.41	€124.44
5%	€89.75	€127.80
6%	€93.34	€131.53
7%	€96.94	€136.02
8%	€100.77	€140.20

10.2.3. Cost Benefit Analysis

The importance of the cost-benefit analysis has already been explained. Comparing only the external cost per transport option to the concepts' service reveals very significant potential external cost savings. For a TEU, at least €179 can be saved. A FEU transported via the concepts can save at least €179.50, and a HC container can save at least €155.50. All cases are based on transport to/from Bielefeld via Dortmund. Table 10.18 lists the minimum amount of external costs that can be saved per box per destination. Overestimation is best prevented by using the minimum. Following the 30/40/30 share of TEU/FEU/HC, the weighted average of external cost savings per box becomes €207 per box. Multiplying this saving by the amount of boxes transported per annum creates the undiscounted external cost savings, which are approximately €34.7 million. Discounting external costs is debated similar to the way in which external effect valuation is debated. For instance, Schroten et al. [2014] have discounted by 3%, while DG MOVE [2014] uses a discount range of 3–5%. Again, discounting decreases the future value. In keeping with the aforementioned financial discounting, a 6% discount rate is also applied this time. The NPV of external cost savings adds up to €21.7 million. If a higher discount rate were applied, the results would be €16.5 million (10%) and €12.2 million (15%). Figure 10.8a depicts the annual external costs savings, 10.8b shows the cumulative cost savings for these three discount rates.

Table 10.18: Minimal external cost saving per container type per destination

Destination (via terminal)	TEU	FEU	HC	Average	Weighed Average
Osnabrück (Hengelo)	€274.50	€275.50	€251.50	€267.17	€268.00
Münster (Hengelo)	€194.50	€185.50	€161.50	€180.50	€181.00
Bielefeld (Dortmund)	€179.00	€179.50	€155.50	€171.33	€172.00
Average	€216.00	€213.50	€189.50	€206.33	
Weighed Average	€216.00	€213.50	€189.50		€207.00

These savings are of course beneficial to society as a whole, but for the concept operator they are difficult to monetize personally. The terminal can demonstrate the external cost savings it can achieve compared to the competition and thereby attract or persuade cargo owners to use its terminal and vessel. For the investor, however, a subsidy from policy/politics might be far more interesting. If a 6% discount on the NPV of external costs is presented to politicians, they will recognize that a significant impact can be made on the reduction of the external effects of transport. To promote this initiative, they might be wiling to grant a subsidy.

These subsidies come in two types: material and financial. These subsidies can be either upfront (economically sustainable) or over time (economically uncertain). Assuming that the form of the subsidy (whether land and permits or an interest free loan) does not matter, when the subsidy is received is of importance. An upfront subsidy is relatively certain. If a parcel of land is provided, this cannot be taken away easily. A subsidy in terms of a fee per box shipped will, however, be paid out over time. In 15 years of operation, the perspective and/or valuation of policy/politics can change drastically. The investor will have no right to a subsidy when policy/politics terminates the subsidy arrangement. This funding then reverts to zero and no more benefits are gained.

A fair subsidy for the external cost NPV could be, for instance, 5% of the total savings. This would translate to €1,080,000. If the subsidy is paid upfront, the parcel, quay, and landside transfer area could be acquired for free, lowering the financial investment required from the bank and the private investor. If the subsidy were equally subtracted from the three investments, the cost levels at a 6% discount rate come down from €96 (handling) and €134.50 (sailing) to €91.50 (handling) and €128.75 (sailing). This might seem like a marginal reduction, but it will result in an additional €10 margin per box, resulting in the possibility of lowering the tariffs by approximately €10, the result being that the terminal will become even more attractive, leading to more diverted transport, more savings, etc.

These savings do not stand alone and therefore do not necessarily reflect all effects. The diversion of containers from the existing transport chains to the concept tandem leads to a change of location in terms of where emissions occur. Vessels currently sailing will potentially see a decrease in the average loading degree, which will negatively impact their external cost performance. The location of the Ladbergen terminal will result in more truck traffic in and around Ladbergen. Even though traffic does not have to cross the city center, exhaust gasses, congestion, and accidents will increase on a local level. Elsewhere, these effects will decrease. It is difficult for a basic CBA to forecast the relation between this shift in effects.

The shortage of truck drivers that currently perform long-distance haulage or medium-distance PPH to existing terminals will be reduced when container transport over those terminals decreases. For the Ladbergen area, more containers will lead to more demand for truckers. This will positively influence local employment opportunities.

One effect hitherto left unmentioned is the positive influence on the concept terminal's business environment. Hosting an inland container terminal will have a positive effect on the business climate. More businesses will open in the vicinity of the terminal. Examples of such businesses include additional trucking services, a less than container load (LCL) handling service, container repair, warehousing of contents, etc. The increased business climate will increase ground prices and therefore be beneficial to the Ladbergen community. New companies will create demand for labor and therefore increase local productivity overall.

The price impact of all of these effects is not calculated in this thesis, since the construction of a detailed CBA is a field of study on its own. By discussing many important decisions variables, the potential impact of starting the container transport service to Ladbergen is demonstrated. At the same time, it is prevented to give a wrong impression by using or proposing misrepresentative numbers.

10.3. Intermediate Conclusions Chapter 10

Results throughout this chapter have demonstrated that for an assumed favorable case, the concept terminal and concept vessel(s) can operate at a competitive cost level. This is, however, under the assumption of 18,000 TEUs of annual volume from container owners who can potentially be persuaded to make a mode shift.

The rural location offers great opportunities for development and accessibility. Locating the terminal is a delicate task, however. Shifting the terminal to the north and therefore nearer to Osnabrück lowers the PPH distance to both Osnabrück and Bielefeld; however, the distance to Münster increases. The cost level difference with Münster is already the most critical, so in that respect, the terminal would best be shifted towards Münster.

If the terminal concept became a true success, a competitor might find a location along the Mittelland Canal between Bielefeld and Hanover and build a terminal there. This would then negatively impact the first terminal's operations. Locating the terminal wisely is both important and delicate in the short term and the long term.

Competition with large CEMT ≥ Va class vessels can only be achieved by decreasing the PPH distance required. The lower PPH costs, and therefore the "savings," must be higher than the additional sailing and handling costs. This thesis focuses on small-scale applications, and due to the concave cost functions it is virtually impossible to operate a terminal at volumes ≤ 10,000 boxes per annum. In such cases, the costs per box are so high that the decreased PPH distance cannot mitigate this increase.

Whereas current small-scale terminals are advised to grow to approximately 50,000 TEUs (30,000 boxes) per annum, in this case the advice would be to try and grow to 12,000 boxes as soon as possible in order to be able to offer sufficiently low handling costs to reach economic feasibility.

It would therefore also be economically infeasible to propose small-scale terminals in both Münster and Osnabrück for the assumed volumes, especially because some PPH will always remain, and the PPH call-out costs lead to a concave costs curve over distance for PPH as well. In this case, the last-mile problem is difficult to mitigate.

At the same time, it has been demonstrated that high-cube containers can lead to problems on small waterways with a maximum air draught. If the Dortmund-Ems Canal was equipped with movable bridges, HCs could be transported without restriction. Allocating true costs to those boxes will make competition impossible. It may therefore be best to accept the HC presence and increase the costs per regular TEU and FEU instead. The exact cost allocation and/or price setting will be determined by the eventual operator/investor of the terminal.

The results also demonstrated that realized volumes are of greatest importance to the feasibility. Building a terminal and buying a vessel that is too large will lead to substantially higher costs. These cost levels will mean that hardly any containers can be attracted. In such a scenario, large negative cash flow would have to be incurred because revenue falls short of costs. Only then might transport volumes increase, eventually increasing revenues. This will require deep pockets and seriously impact the overall return.

11 Conclusions

This thesis began with background information outlining concerns regarding road-based congestion and exhaust gas emissions caused by truck haulage. Inland shipping forms, together with rail transport, comprise the competition of road-based transport. On a large scale, very large inland vessels that can transport cargo at very low cost levels can perform waterway container transport. Economies of scale are the primary reason for these low cost levels. In the current market, excess capacity of large vessels has led to decreased prices. As a result, the operating margins have deteriorated, and financially healthy operations have become more difficult.

What these vessel lack is the possibility to enter a new market, to penetrate the capillaries of the inland waterway network. Currently, however, there are no competitive small waterway container transport concepts either in operation or even being designed. This thesis therefore proposed concepts that will take advantage of this potential niche market.

The scalable container carrier concept (SCCC) series offers a most efficient vessel capable of operating under all different conditions. The scalability was demonstrated to enable sufficient capacity depending on waterway and annual capacity limitations. The results from Section 9.5 particularly demonstrated the impact of changings parameters on the cost level and thereby the economic performance capabilities of the SCCC series.

In parallel with the absence of a dedicated small-scale vessel, no (very) small terminal concept was found that could operate at a competitive rate. The existing concept that seemed to most resemble the small-scale application is the NGICT. In reality, however, this terminal would also operate best in an environment with higher volumes. Additionally, its superior stacking density is not required in a rural, low-cost environment.

Eventually, the most promising result was found to be the rolling conveyor concept (RCC). Its superior scalability enables a sufficient container terminal design for virtually all possible small-scale business cases. At the same time, the scalability enables a cost level reduction if significant growth is realized. By increasing the alley length, the number of alleys, and the rack height, the terminal can increase its slot capacity. Increased sailing frequency will also limit the required capacity growth because the terminal will be used more efficiently. With the small-scale inland vessels, an increase in call frequency is quickly realized when the demand for transport increases.

Gained understanding of the small-scale container inland shipping market was used to counter the problem formulated in the problem statement. The problem statement is repeated below:

There is not currently an automated inland concept that focuses on transport of cargo with vessels on waterways (CEMT IV and smaller) with the ability to self-(un)load and be competitive with rail, road and large scale IWT.

The concept terminal is designed for automated operations. No labor other than a ship-based supervisor for safety and first-line maintenance is required for operations. If the same company owned the terminal and vessels, the inland vessel captain could even be trained to verify terminal proceedings.

The hatch coaming gantry crane (HCGC) is able to (un)load containers in cooperation with the quay platform. The vessel's crew will control this loading procedure. They are not, however, required to manually operate the crane. Riding across the hold and lifting and transferring containers can all be accomplished without human interference. A real-time stability computer can prevent situations in which stability becomes critical. The vessel's crew will monitor the process and intercede if necessary.

Competition-wise, the author decided to exclude rail as a competing mode in Chapter 3. Rail presence is dependent on location and a completely different business. For very small call sizes, building additional infrastructure is almost never economically feasible. Of the current inland terminals, only those near existing tracks offer this mode as a service.

With the creation and feasibility checks of both concepts, the objective is reached. The formulated objective is repeated below:

The goal of this research is to design a ship and corresponding terminal concept in order to decrease congestion. The concept must be automated, simplistic, competitive, and profitable during the process steps, transport, storage, and handling of cargo.

The concepts proposed are automated, simplistic, competitive, and profitable during the process steps of cargo transport, storage, and handling. Decreasing congestion is the most difficult objective to reach. The fact is that by using the terminal and vessel concepts instead of current inland terminals, PPH distances are shortened drastically. Reduced distances automatically mean that less vehicle kilometers have to be travelled per shipment, leading to a reduction in the amount of time a PPH truck is on the road or in the total number of trucks required to perform PPH. Section 2.3 referred to both transport and traffic as similar but not the same. The reduced PPH distances will decrease and redirect traffic, while at the same time keeping transport the same or even allow it to grow.

At distances ≥ 250 km, the cost gap between current long-haul trucking and CEMT Va increased significantly in favor of inland shipping, yet long distance trucking is widely used. Several reasons for this have been provided. The individual VoT of the contents might be high, additional transport costs might be mitigated over the amount of goods inside, or the transport manager might be unaware of or unfamiliar with inland shipping services. For the first two explanatory motives, the concept tandem cannot offer a radically different alternative to persuade the goods owner. With respect to the latter, the concept does offer a revolutionary transport alternative in terms of ease of use and cost competitiveness. Those who currently use long-distance truck haulage for Blue Corridor container transport will have a new, cost-reducing alternative that is worth researching.

This is all to say that for any container that is taken from the road, especially those transported via long-haul services, it is not only preventing the truck from making a single trip; the return trip is also prevented. From an external effects point of view, the truck returning empty during rush hour is a worst-case scenario. The route between Rotterdam and the Münster/Osnabrück/Bielefeld area passes several large cities with recurring congestion on their ring roads. Every truck that can be removed from that route by offering a better alternative will reduce congestion.

What remains is to answer the main research question, as shown below:

Can a feasible design for both ship and terminal be designed that can revitalize small vessel transport on small inland waterways, and if so, what will this design look like?

Here feasibility is defined as automated, simplistic, competitive, and profitable during the process steps of transport, storage, and handling of cargo. Small vessels and small inland waterways are both defined as CEMT ≤ IV.

The main question can be answered affirmatively. It has been thoroughly demonstrated that feasibility can be achieved for a favorable and realistic case. The feasibility is case dependent and therefore it cannot be guaranteed that the concept(s) will always be feasible. Finding a niche market such as the one in the favorable case enables both the SCCC and SCHC to flourish. It is highly likely that, in addition to the case discussed, other environments can be found in which the concepts can offer a lower cost solution. Two explanatory cases worth researching are discussed in the recommendations made in the next chapter.

Revitalizing small vessel transport on small inland waterways (both CEMT ≤ IV) can only be accomplished via a competitive edge over truck and/or CEMT ≥ Va. Inland waterway container transport using large vessels on primary waterways (both CEMT ≥ Va) can be performed at very low costs. The large-scale terminals these vessels use can also offer low cost handling. Altogether, the concepts are best used in an environment where primary waterways are relatively far away (e.g., more than 50 km (straight line) away from a CEMT Va inland terminal, and even further from a terminal accessible by Jowi-class vessels).

One of the other important conditions for success with regard to revitalization is small waterway conditions. The French canals have been poorly maintained, decreasing the effective capacity. Upgrading the Dortmund-Ems Canal so that it could be sailed by elongated CEMT IV vessels is very important in terms of cost level reduction. Previously, the canal could only be navigated by vessel up to 86 meters in length. With the increased capacity, 105-meter vessels are allowed to navigate the canal. For the SCCC in the Ladbergen case, this increased capacity allowed the use of all lengths. An *"XY13"* could therefore be used instead of an *"XY10"*. The increased dimensions and resulting carrying capacity enables the concept vessel to significantly reduce its cost level as found in Subsection 9.5.2.

In addition, it has been demonstrated that, with the utmost effort, terminal costs can be reduced rather significantly compared to existing terminal designs. Due to the concave cost function with respect to handling volumes, the concept terminal also has its cost level limitations. At an annual volume of 10,000 boxes, the concept terminal is forecast to be able to operate at an industry acceptable and thereby competitive rate.

Whereas the favorable case allowed the larger SCCC vessels to reach the terminal, there are also cases in which smaller SCCC have to be used. These smaller vessels will have higher costs and will be able to carry fewer containers. For such a scenario it is even more important to move away from the main waterways and penetrate deep into the capillaries of the inland waterway network. When this turns out to be beneficial, small waterways should be navigated as far upstream as possible. When the smaller waterways meander rather extremely, the effect of additional upstream navigation is to a large extent lost. These are all cases that have to be taken into consideration.

Existing terminals were advised to grow to 30,000 boxes per year in order to be able to offer a competitive handling rate. For the concept terminal, similar competitiveness can be reached at 12,000 containers per year. Lowering cost levels even further in order to compete with the large inland terminals would require 18,000 boxes per year and three or more calls per week.

Storage fees, truck-truck use, and additional services at the terminal were all left out of this study. If these elements were incorporated, the utilization efficiency of the terminal could increase further, reducing the 18,000 shipping container goal.

12 Recommendations

The main question was answered, and the feasibility was found. Performing a first sensitivity analysis in Subsection 10.2.2 demonstrated the impact of some of the variables. In the favorable case, annual volumes, terminal location, financing, etc. were all estimated based on reference values. Whether or not the proposed business case can actually be economically operated is still relatively uncertain. No definitive market study, business plan, or engineering of the vessel series or the terminal has been conducted. As a result, the true costs may differ from the assumed costs and change the positive margin found to a (slight) negative or indifferent margin.

This thesis found feasibility for a (very) modest assumption with regard to the shipped annual volume. Performing a market study for the area of interest is advised as the next step. In this case, this means getting in contact with the larger, known container importers and exporters in the Münster/Osnabrück/Bielefeld area in order to learn what their volumes and paid prices are. Additionally, this information could be used to learn about hidden and revealed preferences, personnel likings , and other decision variables that are important to transport managers. The best option would be to find what is called a starting client who is willing to give the investor the benefit of the doubt. A statement of the investor's intention to ship all of his/her containers via the concept terminal would lead to a degree of certainty.

Another option would be to focus on the PPH linkage. Some existing haulage firms are active around the terminal location in Ladbergen. A researcher could liaise with them to find out what their interests are and whether or not there is a common pioneering spirit to be found.

A more general recommendation is to thoroughly engineer and simulate terminal dimensions, proceedings, and costs. This study used existing technology that was transferred to a container terminal application. Contact with the NGICT concept owners revealed that even though they have advanced 3D drawings, they cannot provide detailed engineering or precise costs. Finding partners to help with the development is very important to this step. At the same time, the concept should likely be patented, since it might turn out to be the invention of the century.

One of the questions this thesis does not answer is what the best place to start this concept is. Ladbergen and the Münster/Osnabrück/Bielefeld area were chosen based on the preliminary results of Chapter 9. Feasibility was then determined to be achievable for this case. Other interesting locations could include Zutphen in the Netherlands. Ziel [2017] has found substantial cargo volumes present but has not incorporated the superior concept designs created in this thesis. From a research perspective, it would be very interesting to determine whether or not both concepts can work around/mitigate the problems Ziel [2017] found when using existing transport options.

Another location of interest would be Minden (Germany), which is located at the crossing of the Mittelland canal and the Weser. This location might be capable of capturing Bielefeld and Hanover, which are both large German cities. As the continental container flows demonstrated, there is little transport between the Rhine-Delta and the Hamburg-Berlin area via inland shipping. From a niche perspective, it might be worthwhile to research whether or not the concepts could increase interregional container transport.

The focus of this study was limited to small-scale applications. There are also CEMT Class Va waterways that do not currently have a container terminal at each feasible location because no cost-competitive terminal can be built based on existing terminal designs. Researching the applicability of large(r) scale applications is therefore recommended.

A business case build on a round trip across multiple inland concept terminals would also be worth researching. On large waterways, such trips are often not worth the extra time and distance, because sufficient volumes can be obtained at just one or two inland terminals. For a small-scale case in which, for instance, five concept terminals existed, it might be feasible to increase the call frequency by having vessels stop at each terminal. This would be comparable to a public transport service with regular arrivals at each stop.

Inter Blue Corridor container transport, meaning containers that find both their origin and destination within the delta, has to a large extent been left out. The current market is heavily fixated on the ARA container services. Bypassing these deep sea terminals and directly connecting economically active regions within the delta might be worth to pursue. Using the SCHC at both ends of the SCCC voyage will lead to twice incurred high handling costs. Only if substantial container volumes for both the SCCC and SCHC are forecast this new transport alternative is worth researching. Whether such a niche currently is present within the Blue Corridor is still unknown after the literature review.

V

Appendices

A

Inland Vessel Specifics according to CEMT system

Table A.1: Specifics of normative motor-freight ships

CEMT class	breadth (m)	length (m)	draught (m)		air draught (m)	hold capacity (tons)	engine power (kW)	bow thruster (kW)
			loaded	empty				
I	5.05	38.5	2.5	1.2	4.25	365	175	100
II	6.60	50 - 55	2.6	1.4	5.25	535 - 635	240 - 300	130
III	8.20	67 - 85	2.7	1.5	5.35	910 - 1250	490 - 640	160 - 210
IV	9.50	80-105	3.0	1.6	5.55	1370 - 2040	750 - 1070	250
Va	11.40	110 - 135	3.5	1.8	6.40	2900 - 3735	1375 -1750	435 - 705
VIa	17.00	135	4.0	2.0	8.75	6000	2400	1135

Table A.2: Class specifics of motor-freight vessels

CEMT class	air draught 90% (m)		Average holdcapacity (tons)	Average enginepower (kW)
	empty	loaded		
I	4.65	3.35	365	175
II	5.80	4.60	540	250
III	6.30	5.10	935	435
IV	6.70	5.30	1505	690
Va	7.10	5.40	2980	1425
VIa	10.00	8.00	5125	2015

Table A.3: Container capacity several CEMT ships

Shipclass or type	Container capacity			
	Width	Height	Length	TEU
II/III	2	2	7	28
Neokemp	2	3	8	48
IVa	3	3	10	90
Va	4	4	13	208
Va elongated	4	4	17	272
Vla	6	4	17	408
E I - barge	3	3	9	81
E II - barge	4	4	10	160

Table A.4: Specifics of normative dumb barges

CEMT class	Barge type	breadth (m)	length (m)	loaded draught (m)	payload (tons)
IV	Europe I	9.5	70.0	3.0	1450
Va	Europe II	11.4	76.5	3.5	2450
Va	Europe IIa	11.4	76.5	4.0	2780
Va	Europa IIa enlargered	11.4	90.0	4.0	3220

Table A.5: Class specifics of dumb barge configurations

CEMT class	Barge configuration	breadth (m)	lenght (m)	loaded draugth (m)	Payload (tons)
I	1 push barge	5.2	55	1.9	≤ 400
II	1 push barge	6.6	60 - 70	2.6	401 - 600
III	1 push barge	8.2	85	2.7	601 - 1250
IV	1 push barge type E I	9.5	85 - 105	3.0	1251 - 1800
Va	1 push barge type E II	11.4	95 - 135	3.5 - 4.0	1801 - 3950
Vb	2 barges type E II long formation	11.4	170 - 190	3.5 - 4.0	3951 - 7050
Vla	2 barges type E II wide formation	22.8	95 - 145	3.5 - 4.0	3951 - 7050
Vlb	4 barges type E II	22.8	185 - 195	3.5 - 4.0	7051 - 12000
Vlc	6 barges type E II long formation	22.8	270	3.5 - 4.0	12001 - 18000
Vlla	6 barges type E II long formation	34.2	195	3.5 - 4.0	12001 - 18000

Table A.6: Class specifics of pushed convoy configurations

CEMT class	Barge configuration	breadth (m)	lenght (m)	loaded draugth (m)	Payload (tons)
I	2 Péniches long	5.05	80	2.5	≤ 900
I	2 Péniches wide	10.1	38.5	2.5	≤ 900
IVb	1 push barge type E I	9.5	170 - 185	3.0	901 - 3350
Vb	1 push barge type E II	11.4	170 - 190	3.5 - 4.0	3351 - 7250
Vla	1 barge alongside type E II	22.8	95 - 110	3.5 - 4.0	3351 - 7250
Vlb	3 barges E II	22.8	185	3.5 - 4.0	≥ 7250

Table A.7: CEMT classification dating from 1992 for waterways west of the river Elbe. [Rijkswaterstaat, 2017a]

Type de voies navigables / Type of Inland waterways	Classe de voies navigables / Classes of navigables waterways	Automoteurs et chalands / Motor vessels and barges — Type de bateaux: caractéristiques générales / Type of vessel: générales characteristics					Convois poussés / Pushed convoys — Type de convoi- Caractéristiques générales / Type of convoy- Générales characteristics					Hauteur minimale sous les ponts / Minimum height under bridges
		Dénomination Designation	Longueur Length	Largeur Beam	Tirant déau Draught	Tonnage Tonnage		Longueur Length	Largeur Beam	Tirant déau Draught	Tonnage Tonnage	
			m	m	m	t		m	m	m	t	m
D'INTERET REGIONAL / OF REGIONAL IMPORTANCE	I	Péniche Barge	38.50	5.05	1.80-2.20	250-400						4.00
	II	Kast-Caminois Campine-Barge	50-55	6.60	2.50	4.00-650						4,00-5.00
	III	Gustav Koenings	67-80	8.20	2.50	650-1000						4,00-5,00
D'INTERET INTERNATIONAL / OF INTERNATIONAL IMPORTANCE	IV	Johan Welker	80-85	9.50	2.50	1000-1500		85	9.50	2.50-2.80	1250-1450	5,25/or 7.00
	Va	Grand bateaux Rhenands/Large Rhine Vessels	95-110	11.40	2.50-2.80	1500-3000		95-110	11.40	2.50-4.50	1600-3000	5,25/or 7,00/or 9,10
	Vb							172-185	11.40	2.50-4.50	3200-6000	
	VIa							95-110	22.80	2.50-4.50	3200-6000	7,10/or 9,10
	VIb		140	15.00	3.90			185-195	22.80	2.50-4.50	6400-12000	7,10/or 9,10
	VIc							270-280 193-200	22.80 33.00-34.20	2.50-4.50 2.50-4.50	9600-18000	9.10
	VII							285 195	33.00 34.20	2.50-4.50	14500-27000	9.10

Table A.8: Classification of all inland vessels according to Rijkswaterstaat 2010, part 1. [Rijkswaterstaat, 2017a]

CEMT-Klasse	Motorvrachtschepen (Motorvessels)							Duwstellen (Barges)			
	RWS Klasse	Karakteristieken maatgevend schip**				Classificatie		RWS Klasse	Karakteristieken maatgevend duwstel**		
		Naam	Breedte	Lengte	Diepgang (geladen)	Laad-vermogen	Breedte en lengte		Combinatie	Breedte	Lengte
			m	m	m	t	m			m	m
	M0	Overig				1-250	B<= 5,00 of L<= 38,00				
I	M1	Spits	5,05	38,5	2,5	251-400	B= 5,01-5,10 en L>=38,01	BO1		5,2	55
II	M2	Kempenaar	6,6	50-55	2,6	401-650	B=5,11-6,70 en L>=38,01	BO2		6,6	60-70
III	M3	Hagenaar	7,2	55-70	2,6	651-800	B=6,71-7,30 en L>=38,01	BO3		7,5	80
	M4	Dortmund Eems (L < = 74 m)	8,2	67-73	2,7	801-1050	B=7,31-8,30 en L=38,01-74,00	BO4		8,2	85
	M5	Verl. Dortmund Eems (L > 74 m)	8,2	80-85	2,7	1051-1250	B=7,31-8,30 en L>=74,01				
IVa	M6	Rijn-Herne Schip (L <= 86 m)	9,5	80-85	2,9	1251-1750	B=8,31-9,60 en L=38,01-86,00	BI	Europa I duwstel	9,5	85-105
	M7	Verl. Rijn-Herne (L > 86 m)	9,5	105	3,0	1751-2050	B=8,31-9,60 en L>=86,01				
IVb											
Va	M8	Groot Rijnschip (L <=111 m)	11,4	110	3,5	2051-3300	B= 9,61-11,50 en L=38,01-111,00	BII-1	Europa II duwstel	11,4	95-110
	M9	Verlengd Groot Rijnschip (L >111 m)	11,4	135	3,5	3301-4000	B= 9,61-11,50 en L>= 111,01	BIIa-1	Europa IIa duwstel	11,4	92-110
								BIIL-1	Europa II Lang	11,4	125-135
Vb								BII-2l	2-baksduwstel lang	11,4	170-190
VIa	M10	Maatg. Schip 13,5 * 110 m	13.50	110	4,0	4001-4300	B=11.51-14.30 en L=38.01-111.00	BII-2b	2-baksduwstel breed	22,8	95-145
	M11	Maatg. Schip 14.2 * 135 m	14.20	135	4,0	4301-5600	B=11.51-14.30 en L>= 111.01				
	M12	Rijnmax Schip	17,0	135	4,0	>= 5601	B>= 14.31 en L>= 38.01				
VIb								BII-4	4-baksduwstel (incl. 3-baks lang)	22,8	185-195
VIc								BII-6l	6-baksduwstel lang (incl 5-baks lang)	22,8	270
VIIa								BII-6b	6-baksduwstel breed (incl. 5-baks breed)	34,2	195

* Bij de klasses I, IV, V en hoger zijn de doorvaarthoogtes aangepast voor 2 respectievelijk 3 en 4-laags containervaart. (doorvaarthoogte op kanalen t.o.v. Maatgevend Hoog Water = 1% overschrijding/jaar)

** De karakteristieken van het maatgevend schip hebben in de lengte een marge van ± 1 meter en in de breedte van ± 10 cm

Table A.9: Classification of all inland vessels according to Rijkswaterstaat 2010, part 2. [Rijkswaterstaat, 2017a]

Duwstellen (Barges)			Koppelverbanden (Convoys)							Doorvaart-hoogte*
	Classificatie		RWS Klasse	Karakteristieken maatgevend koppelverband**				Classificatie		
Diepgang (geladen)	Laad-vermogen	Breedte en lengte		Combinatie	Breedte	Lengte	Diepgang (geladen)	Laad-vermogen	Breedte en lengte	incl. 30 cm schrikhoogte
m	t	m			m	m	m	t	m	m
1,9	0-400	B<=5,20 en L= alle	C1l C1b	2 spitsen lang 2 spitsen breed	5,05 10,1	77-80 38,5	2,5 2,5	<=900 <=900	B<= 5,1 en L=alle B=9,61-12,60 en L<= 80,00	5,25* 5,25*
2,6	401-600	B=5,21-6,70 en L=alle								6,1
2,6 2,7	601-800 801-1250	B=6,71-7,60 en L=alle B=7,61-8,40 en L=alle								6,4 6,6 6,4
3,0	1251-1800	B=8,41-9,60 en L=alle								7,0* 7,0*
			C2l	Klasse IV + Europa I lang	9,5	170-185	3,0	901-3350	B=5,11-9,60 en L=alle	7,0*
3,5 4,0 4,0	1801-2450 2451-3200 3201-3950	B=9,61-15,10 en L<=111,00 B=9,61-15,10 en L<=111,00 B=9,61-15,10 en L=111,01- 146,00								9,1* 9,1* 9,1*
3,5-4,0	3951-7050	B=9,61-15,10 en L>=146,01	C3l	Klasse Va + Europa II lang	11,4	170-190	3,5-4,0	3351- 7250	B=9,61-12,60 en L>=80,01	9,1*
3,5-4,0	3951-7050	B=15,11-24,00 en L<=146,00	C2b C3b	Klasse IV + Europa I breed Klasse Va +Europa II breed	19,0 22,8	85-105 95-110	3,0 3,5-4,0	901-3350 3351- 7250	B=12,61-19,10 en L<=136,00 B>19,10 en L<=136	7,0* alleen voor klasse IV koppelverband 9,1*
3,5-4,0	7051-12000 (7051-9000)	B=15,11-24,00 en L=146,01-200	C4	Klasse Va + 3 Europa II	22,8	185	3,5-4,0	>=7251	B>12,60 en L>=136,01	9,1*
3,5-4,0	12001-18000 (12001-15000)	B=15,11-24,00 en L>=200,01								9,1*
3,5-4,0	12001-18000 (12001-15000)	B>=24,01 en L=alle								9,1*

Opm: 1: Een maatgevend schip is een schip waarvan de afmetingen bepalend zijn voor de dimensionering van de vaarweg en de kunstwerken daarin.
2: Bij nieuwbouw of vaarwegverruiming wordt uitgegaan van het grootste maatgevende schip binnen een CEMT-klasse.
3: Klasse M3, M4, M6, M8, M10 en M11 mag alleen worden toegepast bij renovatie van bestaande vaarwegen, sluizen en bruggen.
4: De kleinste afmetingen van een maatgevend schip vormen de ondergrens om een vaarweg in een bepaalde gestandaardiseerde klasse in te delen.

B

Inland Vessel Types left out

Barges

Push barges in various configurations are a second type. For push barges, the majority lacks the possibility of propulsion. On some barges however, additional propulsion is provided and/or they are equipped with self-powered bow thrusters. This is however limited in many cases. Propulsion for a single barge or combination of barges is provided by a pusher or towboat in push configuration. Figure B.1 below shows an example of such a combination. Barges can be coupled with help of a variety of methods. Some barges are equipped with a recess in the shape of a pusher, others are reliant on cable tension and the latest development make use of hydraulic cylinders. Several barge combinations that are most often found are displayed in the table on page 199.

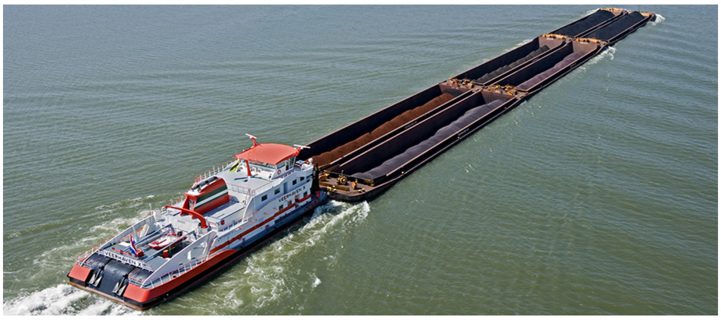
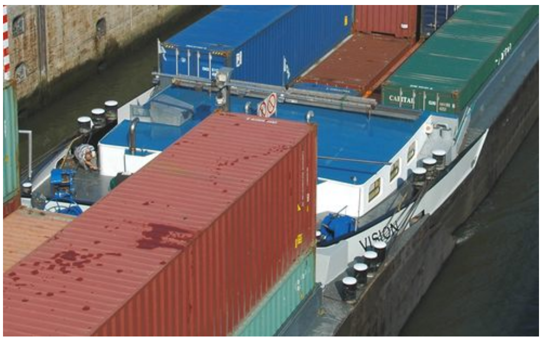


Figure B.1: Six push-barges powered by pusher 'Veerhaven X'. Configations is three barges long by two barges wide. [Gebr. Kooiman, year = unknown]

(a) Hydrologic barge coupling system. [Van Huizen, 2014]



(b) Example of barge with indentation to accommodate and optimize the pushing motorship 'Vision'. [Schuitemaker, 2007]

Figure B.2: Barge coupling examples

Convoys

Third type of occurrence is a combination of the previous two. A ‘koppelverband’, coupled-combination or coupled-convoy is the combinations of a motor vessel and one or more barges. The name for this type was not present in the CEMT documentation, leading to the definition of the name coupled-convoy by Rijkswaterstaat. In Dutch and German the term ’koppelverband’ is commonly used.

Combinations can occur in length directions as well as side-to-side configuration. Choice for such a combination can be made for a variety of different reasons. The example of Figure B.2b is for instance a streamlined combination. Standard barges as seen on Figure B.1 are less streamlined and thus require more power. Another common found combinations is that of a standard inland container vessel, that for some part transports a barge alongside. In the ARA-ports they than first deliver the barge to a specific terminal. Decoupling than enables the motorship to navigate to an adjacent terminal, so that double (un)loading speed can be obtained.

Choice for a certain combination however does depend on the bottlenecks experienced on the route ahead. When there is either a length or width restrictions, the captain has to make the right choice.

Figure B.3: Convoy mv Roxy. [unknown, 2007]

Sea-to-River ship, River-to-Sea ship, creep-line coaster

A fourth type of ship seen within the region of interest is the sea-to-river ship. Sometimes referred to as creepline coaster or sea-river vessel. This is a seagoing vessel, that has a modified design enabling the ship to sail some distance upstream. RWS has however found that the share of sea-riverships is negligible in the total amount of ships navigating the region Rijkswaterstaat. Vessels of this type are frequently used to operate a regular service between an inland terminal such as Duisberg and ports in the UK. This way they can prevent additional transhipping in an ARA-port, reducing costs. In practice are these ships fulfilling niche markets that are not of interest for the remainder of this project.

Figure B.4: Example of a sea-rivership. [Makkum, 2013]

C

Container Loading Efficiency for Non-Dedicated Inland Vessels

Table C.1: Container carrying capacity and corresponding hold use for dry bulk vessels carrying standard TEU containers.

Item\Waterway	Class I		Class II		Class III		Class IV		Class V	
Maximum dimensions										
- Lenght	38.50	m	55.00	m	80.00	m	85.00	m	110.00	m
- Width / Beam	5.05	m	6.60	m	8.20	m	9.60	m	11.45	m
- Height	4.00	m	5.00	m	5.00	m	7.00	m	9.10	m
Hold dimensions										
- Lenght	23.00	m	39.00	m	56.00	m	61.00	m	86.00	m
- Width	3.70	m	5.25	m	6.85	m	8.25	m	10.10	m
- Payload	365	t	615	t	1150*	t	1500*	t	2900	t
Theoretical capacity										
- 20 foot cont. in length	3.77	box	6.39	box	9.18	box	10.00	box	14.10	box
- 20 foot cont. in width	1.48	box	2.10	box	2.74	box	3.30	box	4.04	box
- 20 foot cont. in height**	1.00	layer	2.00	layer	2.00	layer	3.00	layer	4.00	layer
Total Capacity	5.58	box	26.85	box	50.31	box	99.00	box	227.83	box
Guaranteed capacity										
- 20 foot cont. in length	3.00	box	6.00	box	9.00	box	10.00	box	14.00	box
- 20 foot cont. in width	1.00	box	2.00	box	2.00	box	3.00	box	4.00	box
- 20 foot cont. in height	1.00	layer	2.00	layer	2.00	layer	3.00	layer	4.00	layer
Actual Capacity	3	box	24	box	36	box	90	box	224	box
Loading efficiency										
- Volume	53.76	%	89.38	%	71.56	%	90.91	%	98.32	%
- Weight***	10.68	%	50.73	%	40.770	%	78.00	%	100.41	%

*: Payloads calculated with help of linear interpolation based on table A.1 of Rijkswaterstaat [2017a]. **: Kept original layer height of Van Dorsser [2015]. ***: Payload percentage based on 13 tonnes TEU weight for the case of loaded containers only Brolsma [2013].

D

Cost Development of IWT between 1980 and 2015

D.1. Justification and clarification of data gathering method

All numbers based on the work of Van der Meulen and Van der Geest [2016] are the result of their annual market research. With their result a clarification is provided concerning the methodology and market acceptance. Developments in costs are tracked and traces with help of annual figures from inland ship operators. Next to that surveys are conducted.

The specific cost factor such as insurance fees, second hand value and interest rates are the result of cooperation with providers of these services. Since the market cost barometer as it is called is a long running overview. As a result have the compilers gathered experience and a fixed method of working, reducing error in-between years.

Checks to eliminate or reduce the standard error as much as possible are done by having the market check the numbers. In the end Van der Meulen and Van der Geest [2016] therefore concludes that the data is fully accepted by the market.

It can thereby be assumed that these numbers do form a realistic representation of cost levels and development. A remark in place is however that when viewing these number they concern the industry average. Doing better than the market average for the concept does thus not necessarily mean it is the preferred solution based on cost alone. Making such statements should be done with utmost care.

D.2. Cost development of inland reference vessels

This appendix does provide insight in the historical development of IWT costs for four different type of vessels. The first three figures D.1, D.2 and D.3 show cost levels for a small, medium and large dry bulk inland vessel. Fourth figure (D.4) shows the development for a large container inland vessel.

Comparing the 'a' sub-figure for the first three makes clear that the relative share of labour costs are decreasing when the vessel is increasing in size. Reducing the labour cost share can thus be achieved by increasing the size. Additionally it can be seen that the other costs have doubled or tripled between 1980 and 2015, yet their effect is very minimal.

Table D.1: Economies of scale in effect. Costs are for the year 2015

Vessel	Vessel cost per kilometre		Payload		EoS
Type	Absolute	Relative	Absolute	Relative	Rel. Payload / Rel. Cost
CEMT II	€ 80	100%	600	100%	100%
CEMT IV	€ 100	125%	1000	167%	133%
CEMT Va	€ 290	363%	3250	542%	149%

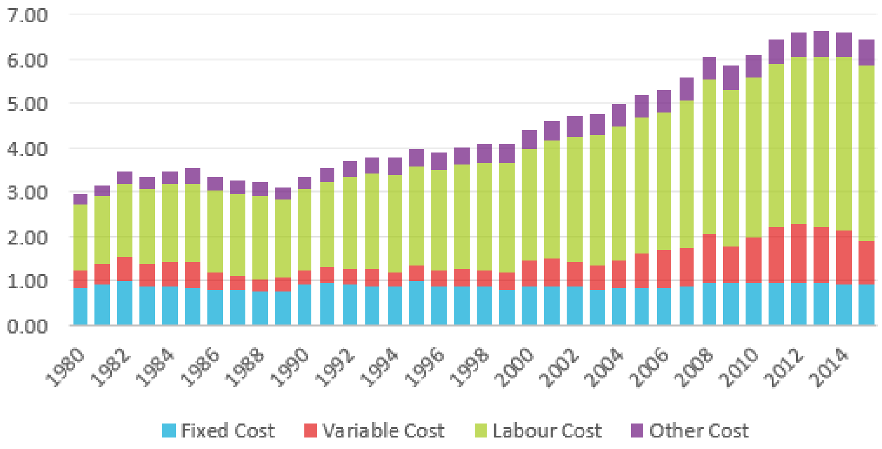
Reviewing all sub-figures ’b’ (for the first three figure) clearly shows the effect economies of scale can bring. Whereas the cost from small to large are increasing 263%, the payload is increasing 452%. As a result the economies of scale can lead up to 49 percent, effectively halving the sailing costs. The offered tariff can than also be almost halved to become more competitive at the same operational margin or can be less than halved to increase the profit margin.

The red, variable cost line in sub-figures ’c’ for all four shows a double peak round 2008 and from 2010 to 2014. This peak is primarily explained by the crude oil price that during these periods rose to record heights. On the long rung do labour costs more than double, the result of the collective wage agreements requiring annual wage increase. From the relative level of 50 to near 140 for the small dry bulk vessel is for instance the result of an annual 3% increase for 35 years.

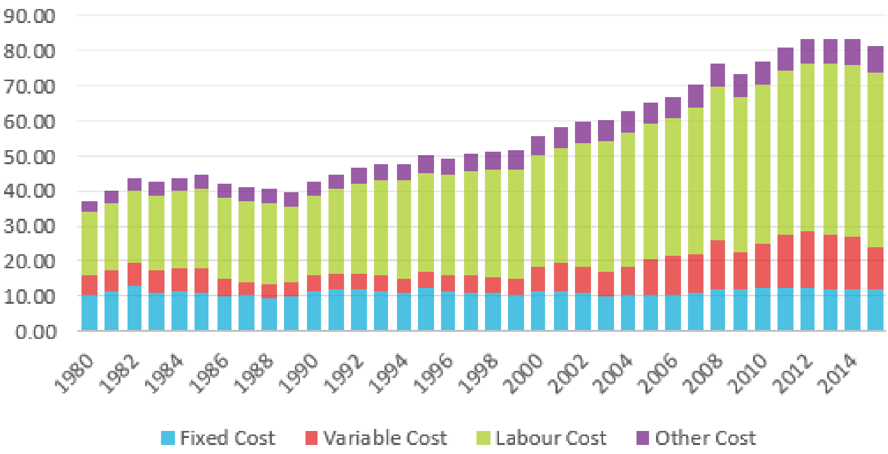
Result of the double peak is that over the past 35 years, variable costs have increase. For all vessels, except the large dry bulk size, have the variable cost developed towards the fixed costs. These two cost factors are in 2015 almost equal to each other. Sub-figures ’d’ show for all four similar trends. That the main cause for increase costs are primarily caused by increased labour cost and secondary by the increase in variable costs.

Analysing possible relations between the large dry bulk and large container vessels (figures D.3 and D.4) leads to following image. The container vessel makes more than triple the annual hours, but its labour costs are 2.5 times that of the large dry bulk vessel. Fixed costs for both vessels differ €70.000 (2015) in favour of the large dry bulk vessel, while the container vessel sails double the distance. Variable costs are higher for the container vessel which could be explained by the increased use. Approximately double the variable costs for double the distance. The result is however that the fixed and variable cost per operational hour are lower for the container vessel, but its personnel cost are higher than for the dry bulk vessel. Result is a €40 per hour difference between the two vessels with different operational profiles.

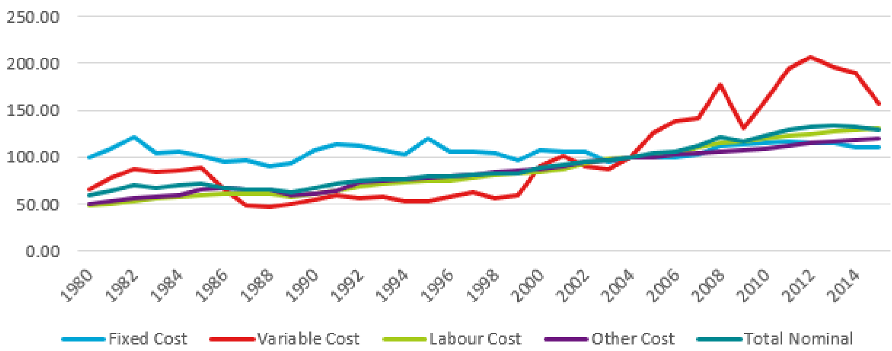
All figures show similar trends over time in which costs are rising. The small and medium vessels have experienced a gradual increase in costs over time, whereas their was a cost stagnation between 1980 and 2000 for the large bulk and container vessel. These larger vessel have increasing costs since 2000. For all graphs a cost maximum is found around 2012. After this costs have come down somewhat due to a decrease in variable costs. Main driver being the reduced oil price since than. Over time are the variable cost likely to rise again with either crude pricing going back up or when adopting the renewable energy sources. These newer drive train solutions are especially on the short to medium term relatively expensive since they are new and not optimized.



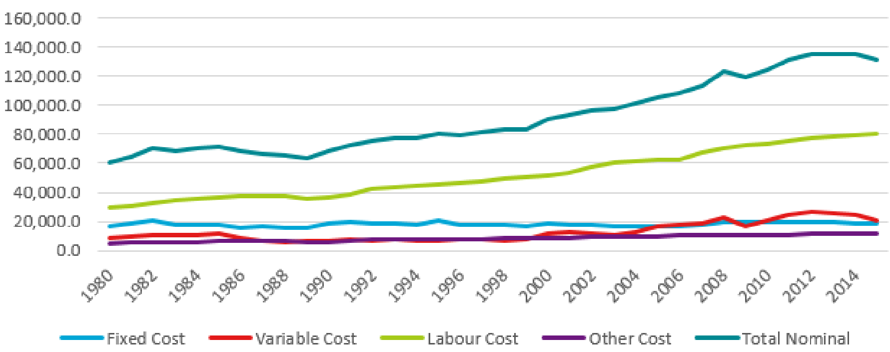
(a) Cost per kilometre. [Van der Meulen and Van der Geest, 2016]



(b) Cost per hour.

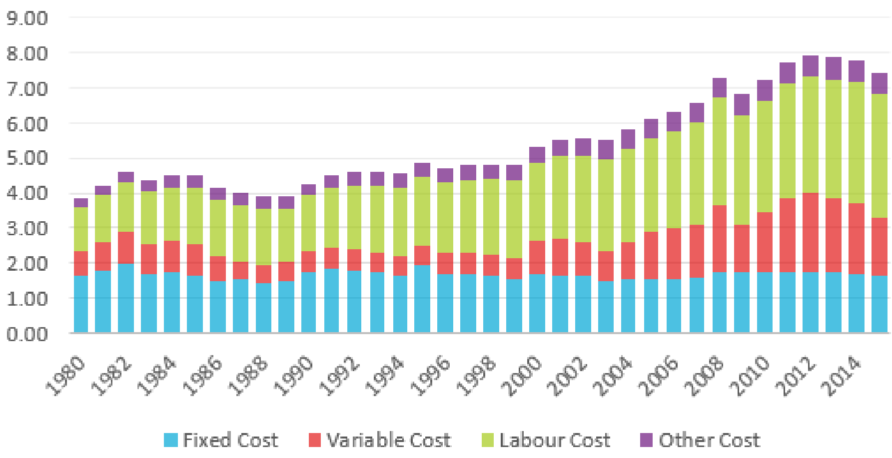


(c) Relative annual cost. (Base year = 2004)

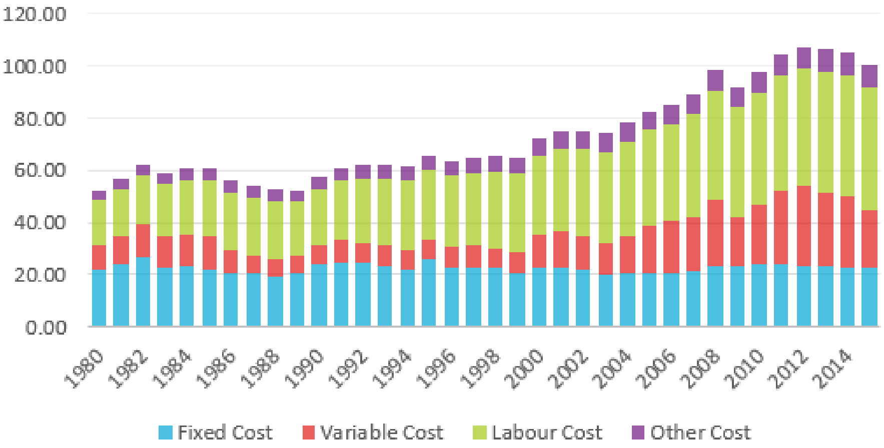


(d) Absolute annual cost.

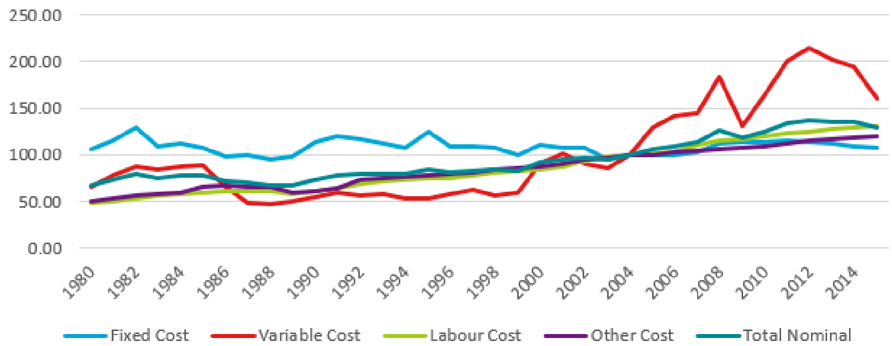
Figure D.1: Costs of a small dry bulk inland vessel. For this vessel the researchers made the following assumptions: Vessel under consideration is the Campine barge, CEMT II. Annual distance covered = 20.362 km with 1616 hours of annual sailing. Averaging the speed at 12.6 km/hour. [Van der Meulen and Van der Geest, 2016]



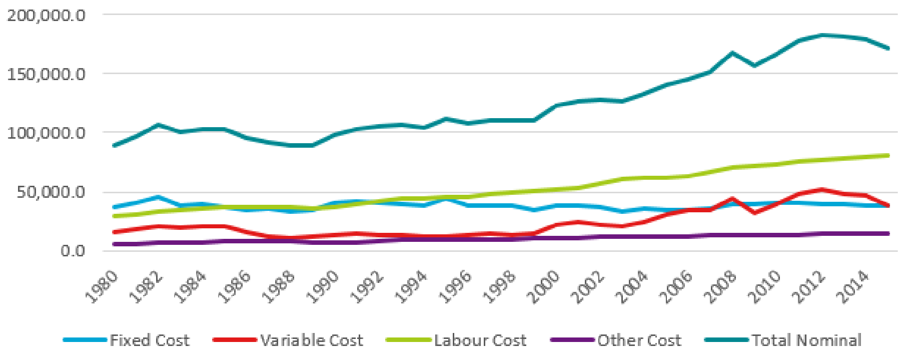
(a) Cost per kilometre. [Van der Meulen and Van der Geest, 2016]



(b) Cost per hour.

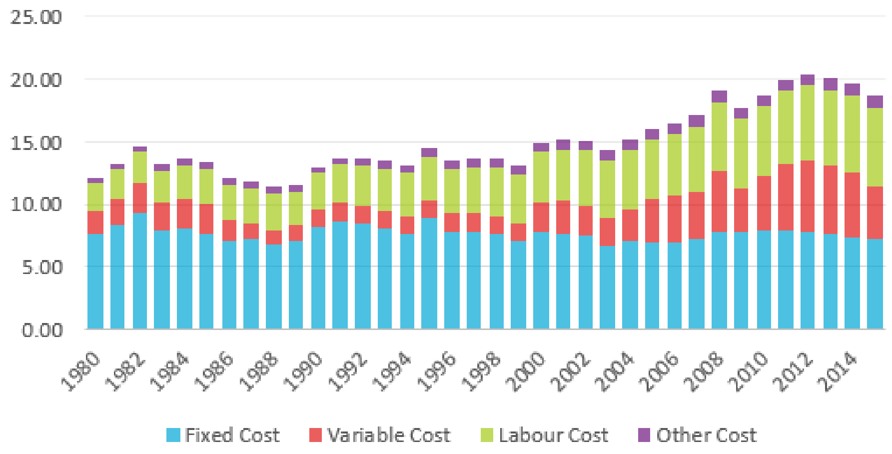


(c) Relative annual cost. (Base year = 2004)

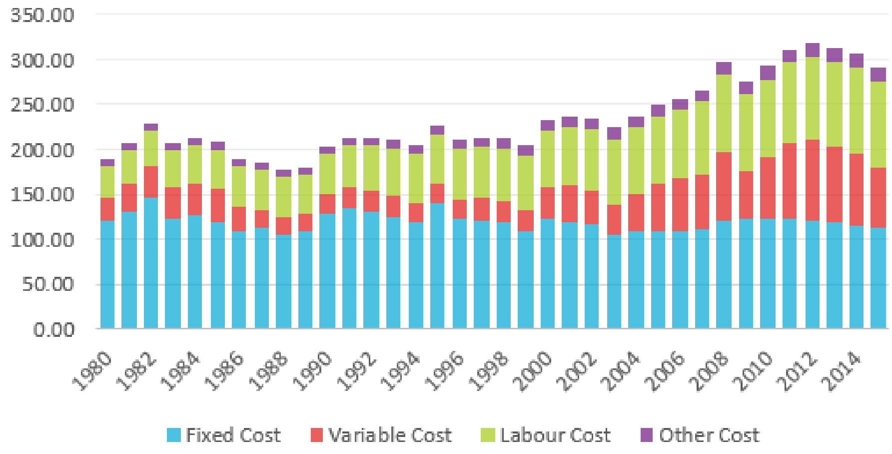


(d) Absolute annual cost.

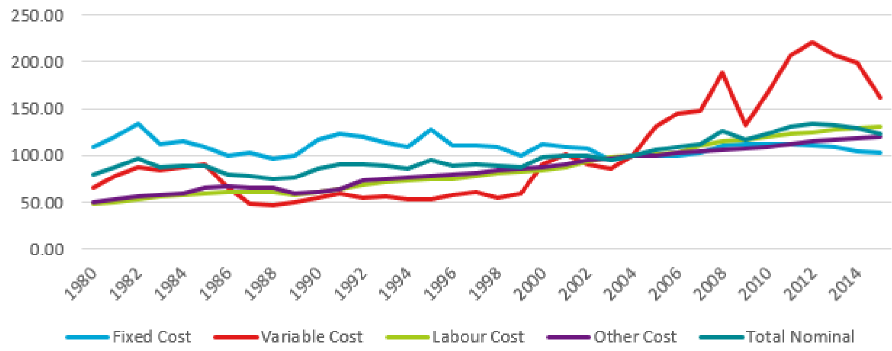
Figure D.2: Costs of a medium dry bulk inland vessel. Vessel under consideration is the Dortmund or Johan Welker vessel, CEMT IV. Annual distance covered = 22.977 km with 1702 hours of annual sailing. Averaging the speed at 13.5 km/hour. [Van der Meulen and Van der Geest, 2016]



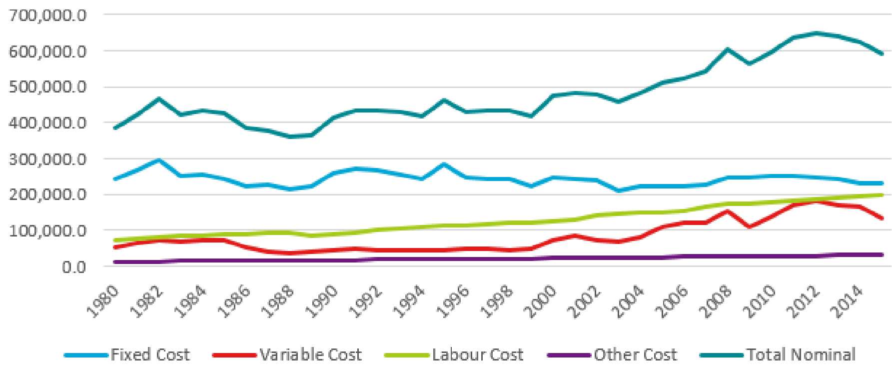
(a) Cost per kilometre. [Van der Meulen and Van der Geest, 2016]



(b) Cost per hour.

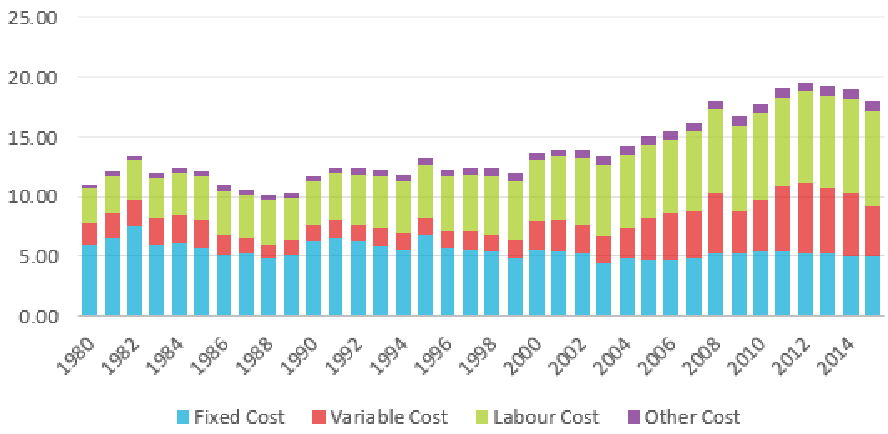


(c) Relative annual cost. (Base year = 2004)

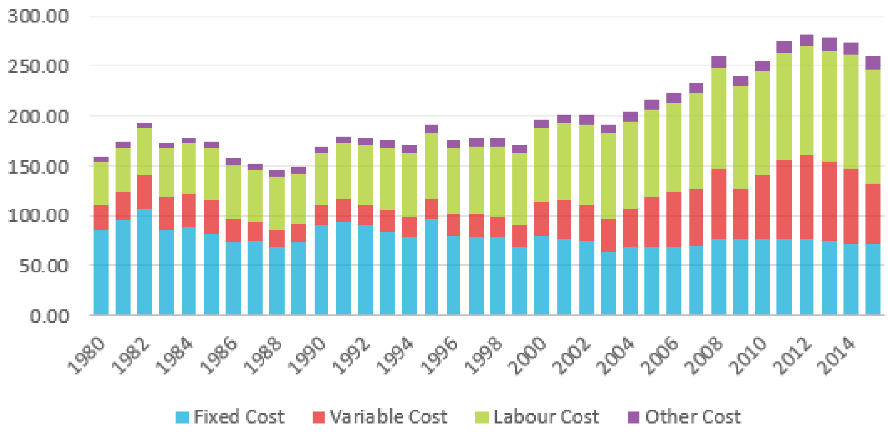


(d) Absolute annual cost.

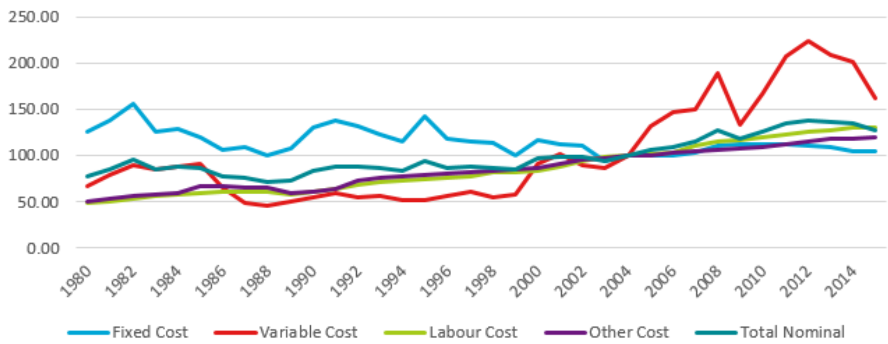
Figure D.3: Costs of a large dry bulk inland vessel. Vessel under consideration is the large Rhine vessel, CEMT Va. Annual distance covered = 31.777 km with 2037 hours of annual sailing. Averaging the speed at 15.6 km/hour. [Van der Meulen and Van der Geest, 2016]



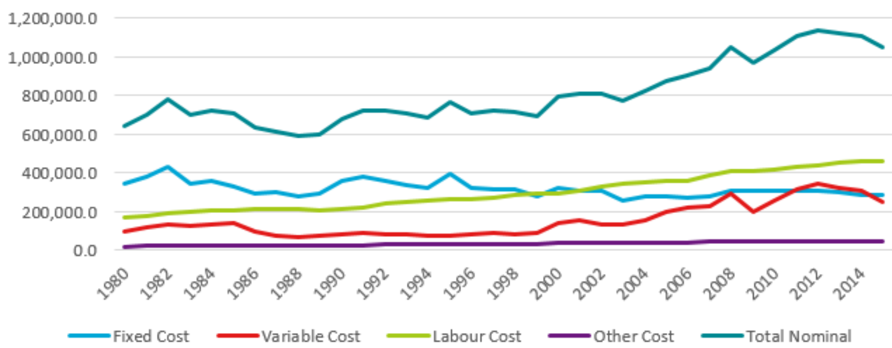
(a) Cost per kilometre. [Van der Meulen and Van der Geest, 2016]



(b) Cost per hour.



(c) Relative annual cost. (Base year = 2004)



(d) Absolute annual cost.

Figure D.4: Costs of a large container carrier. Vessel under consideration is the large Rhine vessel, CEMT Va. Annual distance covered = 58.190 km with 6840 hours of annual sailing. Averaging the speed at 8.5 km/hour. [Van der Meulen and Van der Geest, 2016]

E

Crewing Regulations and Cost

The table below shows the minimum required crew and its composition for navigating on the Rhine. The CCNR [2016] has (as regulating body) come with this rules in order to enable safe operations along the Rhine. The table shows three different operating schemes. A1, A2 and B represent three different operational profiles within a full 24-hour day. These schemes can be adhered following two operational choices being either S1 or S2. S1 requires a standard level of control over the vessel as required by the rules. S2 requires additional bow thruster capabilities which than allow for a less skilled crew.

- A1: Continuous navigation for a maximum of 14 hours per 24 hour cycle.
- A2: Continuous navigation for a maximum of 18 hours per 24 hour cycle.
- B : Continuous navigation for a maximum of 24 hours per 24 hour cycle.

Table E.1: Minimum require crew composition for navigating on the Rhine. [CCNR, 2016]

Length	Crew members	Number of crew members in operating mode					
		A1		A2		B	
		S1	S2	S1	S2	S1	S2
L ≤ 70	Boatmaster	1		2		2	2
	Helmsmen						
	Able boatman						
	Boatman	1				1	
	Apprentice					1	2
70 <L ≤ 86	Boatmaster	1 or 1	1	2		2	2
	Helmsmen						
	Able boatman	1 or 0					
	Boatman	0 or 1	1			2	1
	Apprentice	0 or 1	1	1			1
L>86	Boatmaster	1 or 1	1	2	2	2 or 2	2
	Helmsmen	1 or 1	1			1 or 1	1
	Able boatman						
	Boatman	1 or 0		1		2 or 1	1
	Apprentice	0 or 2	1	1	2		1

The following wage table (E.2) shows three different monthly gross wage tariffs per staff member per vessel length. The total wage table by CBRB [2018] has many column for different cases. There are three wages selected to represent the A1, A2 and B sailing scheme. For the first, A1, operating scheme the lowest wages are selected. A2 includes a 16% bonus for irregular hours. B includes a 24% bonus for irregular hours and 19% bonus for work on saterdays and sundays. As mentioned in subsection 7.5.1 the exact wage is dependent on many factors. It is important to keep in mind that the values below are crew wages and not labour costs. The labour insurances and pension are for instance not included.

Table E.2: Crew wages according to the collective wage agreement for inland shipping personnel. CBRB [2018]

Length (m)		Crew	Monthly Salary A1 14/5	A2 18/5	B 24/7
		boatmaster	€ 2,135.58	€ 2,477.27	€ 3,053.88
		helmsman	€ 1,858.30	€ 2,155.63	€ 2,657.37
0	70	able boatam	€ 1,823.10	€ 2,114.80	€ 2,607.04
		boatman	€ 1,795.83	€ 2,083.16	€ 2,568.04
		apprentice	€ 1,578.00	€ 1,830.48	€ 2,256.54
		boatmaster	€ 2,173.64	€ 2,521.42	€ 3,108.30
		helmsman	€ 1,858.30	€ 2,155.63	€2,657.37
70.01	86	able boatam	€ 1,823.10	€ 2,114.80	€ 2,607.04
		boatman	€ 1,795.83	€ 2,083.16	€ 2,568.04
		apprentice	€ 1,578.00	€ 1,830.48	€ 2,256.54
		boatmaster	€ 2,219.85	€ 2,575.02	€ 3,174.38
		helmsman	€ 1,858.30	€ 2,155.63	€ 2,657.37
86.01	135	able boatam	€ 1,823.10	€ 2,114.80	€ 2,607.04
		boatman	€ 1,795.83	€ 2,083.16	€ 2,568.04
		apprentice	€ 1,578.00	€ 1,830.48	€ 2,256.54

Table E.3: Collective wage agreement gross salaries for Dutch sailing staff. [CBRB, 2018]

Loontabel

Datum van ingang: 1 januari 2018

Brutoloon in €

		Maandloon	Weekloon	Uurloon	Maandloon inclusief toeslagen				
					Onregelmatigheids-Toeslag (OT)		Toeslag Zater- en Zondagen (TZZ)		
					16% OT	24% OT	19% TZZ	19% TZZ + 16% OT	19% TZZ + 24% OT
KAPITEIN	Motortankschepen:								
	laadverm. ≥ 2500 ton	2.520,61	581,68	14,54	2.923,91	3.125,56	2.999,53	3.402,83	3.604,48
	lengte ≥ 86 m	2.459,29	567,53	14,19	2.852,78	3.049,52	2.926,55	3.320,04	3.516,78
	lengte 70-86 m	2.387,79	551,03	13,78	2.769,84	2.960,86	2.841,47	3.223,52	3.414,54
	lengte 56-70 m	2.316,44	534,57	13,36	2.687,07	2.872,38	2.756,56	3.127,19	3.312,51
	lengte < 56 m	2.245,41	518,17	12,95	2.604,67	2.784,30	2.672,03	3.031,30	3.210,93
	Sleep- en duwboten:								
	motorverm. ≥ 1200 EPK	2.467,91	569,52	14,24	2.862,78	3.060,21	2.936,82	3.331,68	3.529,12
	motorverm. 900-1200 EPK	2.379,02	549,01	13,73	2.759,66	2.949,98	2.831,03	3.211,67	3.401,99
	motorverm. 600-900 EPK	2.289,70	528,40	13,21	2.656,06	2.839,23	2.724,75	3.091,10	3.274,28
	motorverm. < 600 EPK	2.200,90	507,90	12,70	2.553,04	2.729,11	2.619,07	2.971,21	3.147,28
	Motorvrachtschepen:								
	laadverm. ≥ 2500 ton	2.263,14	522,27	13,06	2.625,24	2.806,30	2.693,14	3.055,24	3.236,29
	lengte ≥ 86 m	2.219,85	512,28	12,81	2.575,02	2.752,61	2.641,62	2.996,79	3.174,38
	lengte 70-86 m	2.173,64	501,61	12,54	2.521,42	2.695,31	2.586,63	2.934,41	3.108,30
	lengte < 70 m	2.135,58	492,83	12,32	2.477,27	2.648,12	2.541,34	2.883,04	3.053,88
MACHINIST	Sleep- en duwboten:								
	motorverm. ≥ 1200 EPK	2.320,68	535,55	13,39	2.691,99	2.877,65	2.761,61	3.132,92	3.318,58
	motorverm. 900-1200 EPK	2.231,33	514,93	12,87	2.588,34	2.766,85	2.655,28	3.012,30	3.190,80
	motorverm. < 900 EPK	2.143,15	494,58	12,36	2.486,06	2.657,51	2.550,35	2.893,25	3.064,71
	Motorschepen	1.894,05	437,09	10,93	2.197,10	2.348,62	2.253,92	2.556,97	2.708,49
SCHIPPER	Motortankschepen	2.153,63	497,00	12,42	2.498,21	2.670,50	2.562,82	2.907,40	3.079,69
	Sleep- en duwboten	2.073,26	478,45	11,96	2.404,98	2.570,84	2.467,17	2.798,90	2.964,76
	Motorvrachtschepen	2.044,28	471,76	11,79	2.371,37	2.534,91	2.432,70	2.759,78	2.923,32
STUURMAN	Motortankschepen:								
	lengte ≥ 86 m	1.956,21	451,44	11,29	2.269,20	2.425,69	2.327,88	2.640,88	2.797,37
	lengte < 86 m	1.884,27	434,84	10,87	2.185,76	2.336,50	2.242,28	2.543,77	2.694,51
	Sleep- en duwboten	1.884,27	434,84	10,87	2.185,76	2.336,50	2.242,28	2.543,77	2.694,51
	Motorvrachtschepen	1.858,30	428,84	10,72	2.155,63	2.304,29	2.211,37	2.508,70	2.657,37
VOLMATROOS	leeftijd 23 jr. of ouder:								
MATROOS-	Motortankschepen	1.858,30	428,84	10,72	2.155,63	2.304,29	2.211,37	2.508,70	2.657,37
MOTORDRIJVER	Motorvrachtschepen	1.823,10	420,72	10,52	2.114,80	2.260,65	2.169,49	2.461,19	2.607,04
	Sleep- en duwboten	1.814,30	418,69	10,47	2.104,58	2.249,73	2.159,01	2.449,30	2.594,44
	leeftijd onder 23 jr.:								
	3 functiejaren	1.742,03	402,01	10,05	2.020,75	2.160,11	2.073,01	2.351,74	2.491,10
	2 functiejaren	1.582,14	365,11	9,13	1.835,28	1.961,85	1.882,75	2.135,89	2.262,46
	1 functiejaar	1.422,20	328,20	8,21	1.649,75	1.763,53	1.692,42	1.919,97	2.033,75
	geen functiejaren	1.262,64	291,38	7,28	1.464,66	1.565,67	1.502,54	1.704,56	1.805,57
MATROOS	leeftijd 23 jr. of ouder:								
	Motortankschepen	1.831,99	422,77	10,57	2.125,11	2.271,67	2.180,07	2.473,19	2.619,75
	Motorvrachtschepen	1.795,83	414,43	10,36	2.083,16	2.226,83	2.137,04	2.424,37	2.568,04
	Sleep- en duwboten	1.795,83	414,43	10,36	2.083,16	2.226,83	2.137,04	2.424,37	2.568,04
	leeftijd onder 23 jr.:								
	3 functiejaren	1.565,23	361,21	9,03	1.815,66	1.940,88	1.862,62	2.113,05	2.238,27
	2 functiejaren	1.404,84	324,20	8,10	1.629,62	1.742,00	1.671,76	1.896,54	2.008,92
	1 functiejaar	1.245,04	287,32	7,18	1.444,25	1.543,85	1.481,60	1.680,81	1.780,41
	geen functiejaren	1.085,29	250,45	6,26	1.258,93	1.345,76	1.291,49	1.465,14	1.551,96
DEKSMAN	leeftijd 22 jr. of ouder	1.578,00	364,15	9,10	1.830,48	1.956,72	1.877,82	2.130,30	2.256,54
	leeftijd 21 jr.	1.341,30	309,55	7,74	1.555,91	1.663,21	1.596,15	1.810,76	1.918,06
	leeftijd 20 jr.	1.104,60	254,90	6,37	1.281,34	1.369,70	1.314,47	1.491,21	1.579,58
	leeftijd 19 jr.	867,90	200,30	5,01	1.006,76	1.076,20	1.032,80	1.171,67	1.241,10
	leeftijd 18 jr.	749,55	172,95	4,32	869,48	929,44	891,96	1.011,89	1.071,86
	leeftijd 17 jr.	623,30	143,85	3,60	723,03	772,89	741,73	841,46	891,32
	leeftijd 16 jr.	544,40	125,65	3,14	631,50	675,06	647,84	734,94	778,49
LICHTMATROOS	leeftijd 20 jr.	970,45	223,95	5,60	1.125,72	1.203,36	1.154,84	1.310,11	1.387,74
	leeftijd 19 jr.	828,45	191,20	4,78	961,00	1.027,28	985,86	1.118,41	1.184,68
	leeftijd 18 jr.	718,00	165,70	4,14	832,88	890,32	854,42	969,30	1.026,74
	leeftijd 17 jr.	623,30	143,85	3,60	723,03	772,89	741,73	841,46	891,32
	leeftijd 16 jr.	544,40	125,65	3,14	631,50	675,06	647,84	734,94	778,49

F
Marginal External Cost

Primary sources used to determine the marginal external costs is DG MOVE [2014]. The external costs that have been marked by them as quantifiable are listed in table F.1. It can be seen that IWT is cleared from congestion, accidents and noise. Of course these effects do take place from time to time but are not significant enough to be quantified as an externality. Especially the absence of congestion for inland IWT might seem odd given the contents of section 3.1.5. The waiting time for a berth in the ARA-ports is however different than congestion on the waterway itself which results in lowered sailing speeds and time loss. Waiting times do occur, resulting in cost based on the value of time. On the regular rivers and canals congestion is however not present.

The seven external cost factors speak for themselves. Only well-to-tank requires some additional explanation. The production of fuel/electricity is not without additional emissions. This energy production impact is incorporated in the factor well-to-tank point. Not only fuels have this factor, electricity generation at large plant is also in many cases fossil fuel based thus causing external effects.

Third column shows which external cost have the potential to be (or are already) internalised by policy/politics. A congestion tax for trucks could for instance have a significant impact on the operational margins. In the analysis for the feasibility study in chapter 9 the impact of these internalised external costs is included.

It should however be noted that policy/politics is unlikely to charge and thereby internalise the full external value due to a.o. different values per country and lobby efforts by logistic sectors. How much of the externality will be charged is highly uncertain. As a first estimate and assumption 10 percent of the external cost has the potential to be internalised.

Table F.1: Quantifiable external cost factors according to DG MOVE [2014].

	External cost	Pot. Internalised	IWT	Articulated Truck	Train
1.	Congestion	■	□	■	□
2.	Accidents	□	□	■	□
3.	Air pollution	■	■	■	■
4.	Noise	□	□	■	■
5.	Climate Change	■	■	■	■
6.	Well-to-tank	■	■	■	■
7.	Infrastructure	□	■	■	■

The report by DG MOVE [2014] is a very detailed handbook on external costs of transport. Table per external cost factor show great detail. Given the fact that for 7 factors at least three tables have to incorporated have these tables not been incorporated in this appendix. A table with base year 2010 values is provided. These values are translated to 2018 levels in a separate table.

Some external factors have an associated cost level dependent on the location the externality is experienced. These locations are labelled urban, rural and motorway by DG MOVE [2014]. To limit the detail level only the urban and motorway values are used and thus shown in the tables below. The motorways is used for the main leg of the trip and the urban value finds its application in the pre- and post-haulage trips.

Trucks can have a variety of loading conditions. As simplification an empty articulated HGV uses the 14 - 20 t class and a loaded version is valued according the 40 - 50 t table values. Coaches are equipped with EURO VI compliant engines. This is most realistic for the coming quarter century.

Rail is neither 100% urban or motorway like. The rural values are used to estimate the external costs of electric freight trains. External accidents for freight rail are estimated to be 20 eurocents per 1000 vehicle kilometres. These are however extremely rare to occur which is why they are excluded.

External costs related to infrastructure maintenance are very difficult to relate directly to the user. DG MOVE [2014] works shows a great spread in values depending on the country and the method that country uses. Channel maintence in France can for instance differ between 1.99 and 10.39 eurocent per tkm depending on whether it is a large or small channel. Dutch waterways do not have this split but are all valued at 1.58. Which is 20 percent lower than the lowest value in France. As a result it has been decided to eliminate this post due to great uncertainty.

Table F.2: External costs for base year 2010 according to DG MOVE [2014].

	External cost	IWT	Loaded HGV		Empty HGV		Train	Unit measure
			Urban	Motorway	Urban	Motorway	Rural	
1.	Congestion	-	180.5	128.1	180.5	128.1	-	€ct/vkm
2.	Accidents	-	1.1	1.2	1.1	1.2	-	€ct/vkm
3.	Air pollution	1.0[1]	2.1	0.5	2.0	0.3	42.2[2]	€ct/vkm
4.	Noise	-	138.80	8.60	69.40	4.30	1402.40	€/1000vkm
5.	Climate Change	27.3[3]	11.2	6.7	5.3	3.7	126.31[2]	€ct/vkm
6.	Well-to-tank	0.9[4]	4.9	2.9	1.2	1.1	181	€ct/vkm
7.	Infrastructure	-	-	-	-	-	-	-

1 Different unit measure for IWT: €/1000tkm
2 Value for the assumed train weight of 500 t.
3 Different unit for IWT: 27.3 eurocent per litre MDO at €90 / tonne CO_2
4 Interpolated value for DPF + SCR between 650 and 3000 tonnes capacity at €90 / tonne CO_2

DG MOVE [2014] could not use only base values for the year 2010. As a result earlier values were updated with an inflation correction. The calculation inflation for European Project is often between 3 and 5 percent, but actual inflation in the Eurozone has been less the past years. As a result a 3 percent annual inflation correction is selected in line with the earlier extrapolations. The equation below shows how the 2018 can be extrapolated and updated to 2018 values. Resulting values are rounded to one decimal. Superscripts 1 and 2 are similar as in table F.2.

$$\text{Value}_{2018} = \text{Value}_{2010} \cdot (1.00 + 0.03)^{2018-2010}$$

Table F.3: Updated external costs for base year 2018.

	External cost	IWT	Loaded HGV		Empty HGV		Train	Unit measure
			Urban	Motorway	Urban	Motorway	Rural	
1.	Congestion	-	228.7	162.3	228.7	162.3	-	€ct/vkm
2.	Accidents	-	1.4	1.5	1.4	1.5	-	€ct/vkm
3.	Air pollution	1.3[1]	2.7	0.6	2.5	0.4	53.5[2]	€ct/vkm
4.	Noise	-	175.8	10.9	87.9	5.4	1776.5	€/1000vkm
5.	Climate Change	34.6[3]	14.2	8.5	6.7	4.7	160.0[2]	€ct/vkm
6.	Well-to-tank	1.1[4]	6.2	3.7	1.5	1.4	229.3	€ct/vkm
7.	Infrastructure	-	-	-	-	-	-	-

3 Different unit for IWT: 34.6 eurocent per litre MDO at €114 / tonne CO_2
4 Extrapolated value for DPF + SCR between 650 and 3000 tonnes capacity at €114 / tonne CO_2

G

CEMT-classed Inland Waterways within the Blue Corridor

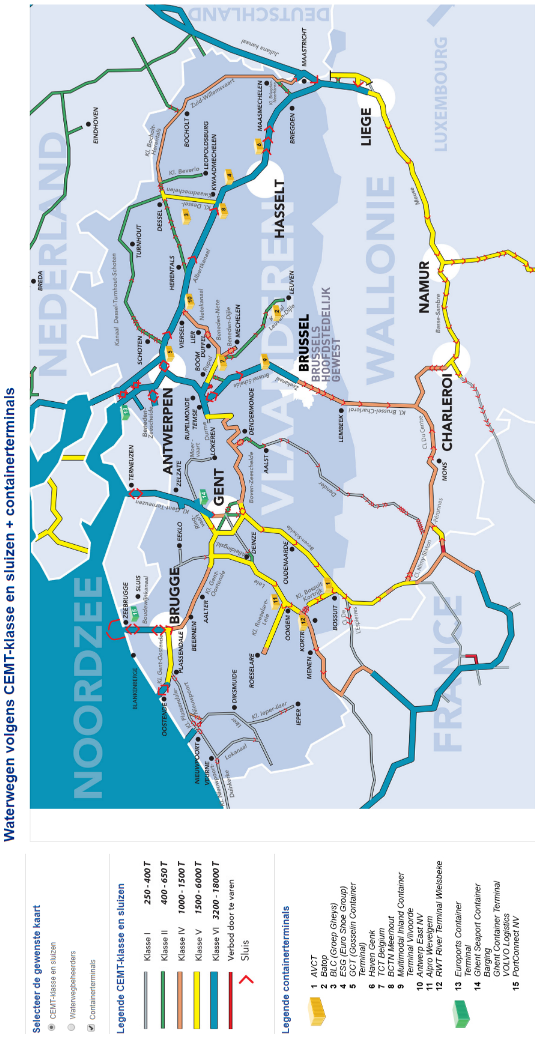
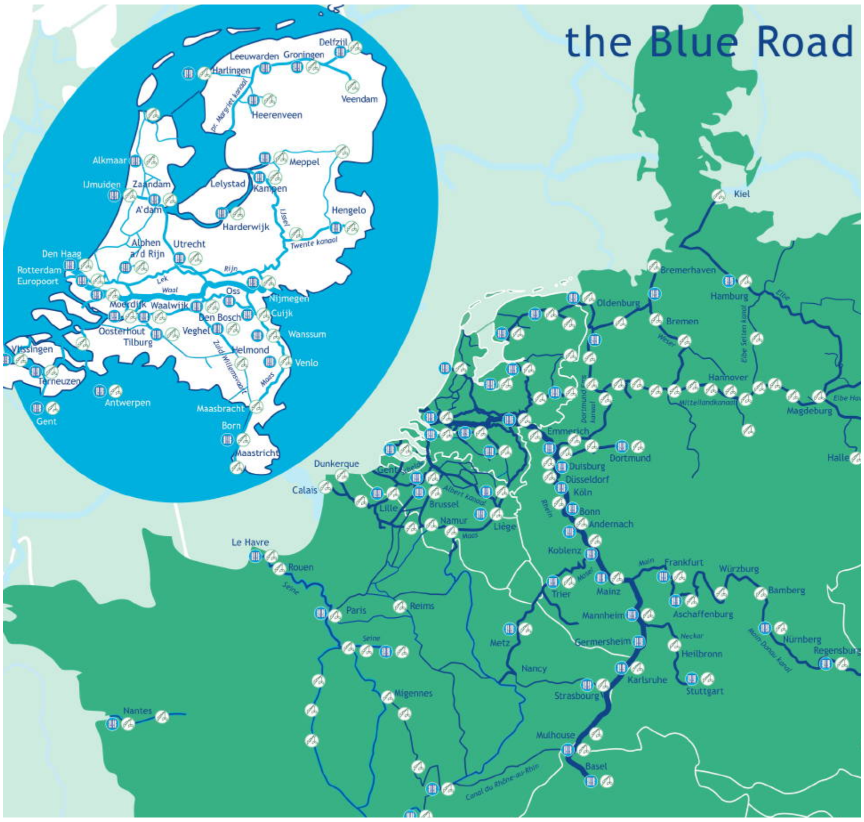
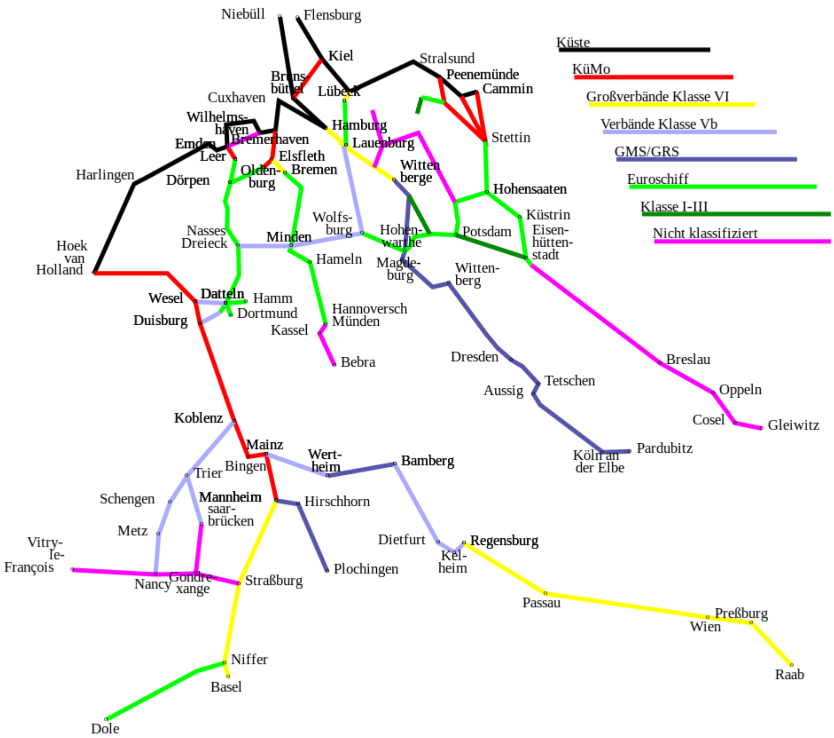


Figure G.1: CEMT class inland waterways of Belgium. (year = unknown) Promotie Binnenvaart Vlaanderen

Figure G.2: CEMT overview of inland waterways in the Netherlands (anno 2009). Legend is in Dutch. First column green bullet: sluizen = sluices. Second column: Aantal scheepvaartpassages = number of ship passings. Third column: Bevaarbaarheid = Navigability with the CEMT class distinctions. [Rijkswaterstaat, 2009]



(a) Overview of important terminals across Benelux and Germany, cut-out from bigger picture containing entire Europe. (base year = 2014) [Bureau Voorlichting Binnenvaart, 2014b]



(b) Abstract preview of German waterway network. (year = unknown) [Ciciban, year = unknown]

Figure G.3: CEMT classed waterways in Germany

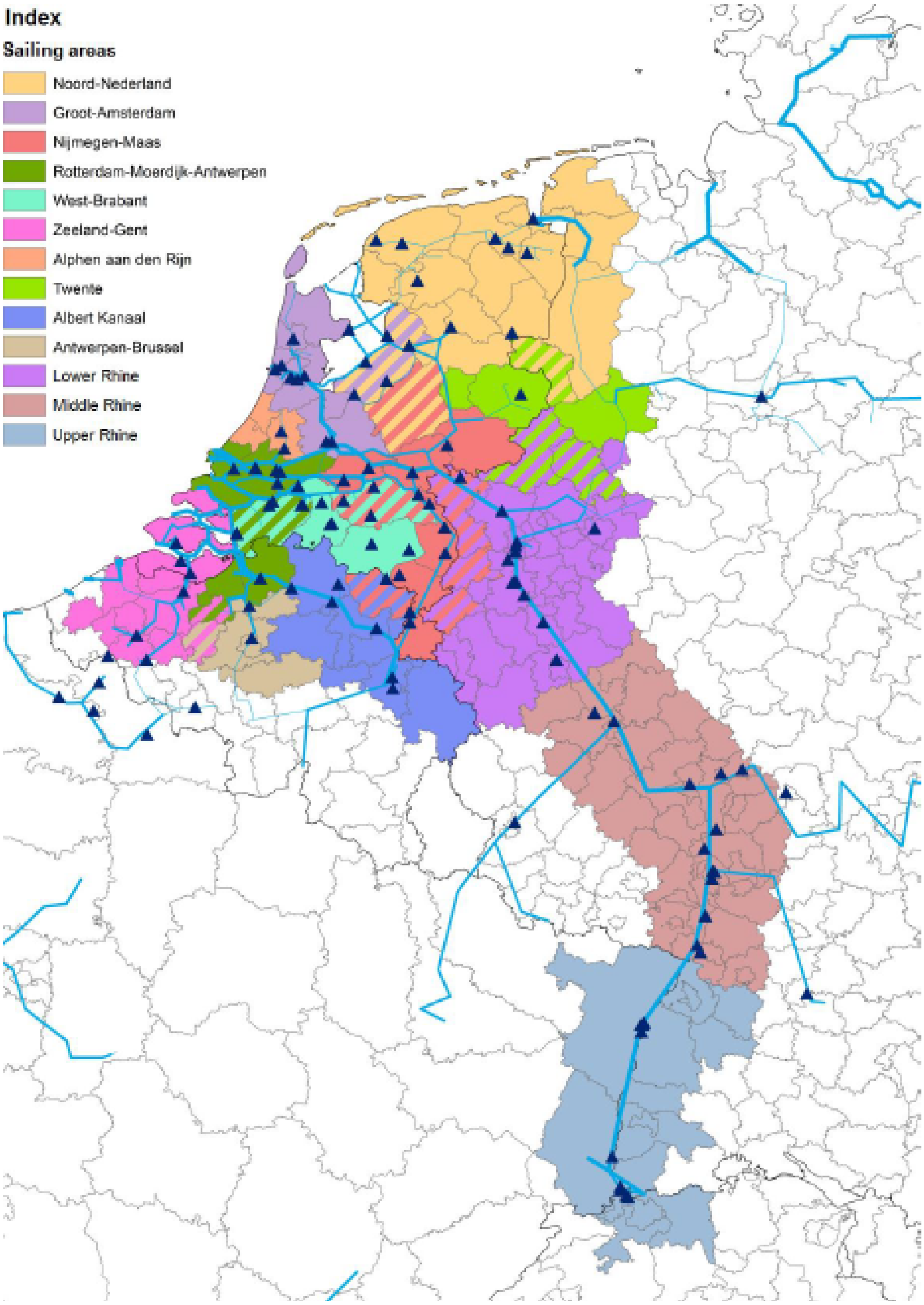


Figure G.4: Current sailing areas with barge service to the Port of Rotterdam. (Base year = 2011) [Van Staalduinen, 2014]

H

Train as Mode of Transport

This appendix provides a brief analysis of train as mode of transport for the Hinterland container networks. It follows the structure applied in section H.1.

H.1. Rail Transport

Additional third mode of interest is the transport by rail. A freight train hauls cargo using freight cars specialized for the type of goods. The result of using a locomotive followed by a number of carriages is that in practice this type of train is scalable. Similar to trucks where the truck and trailer can be separated, train freight transport sees a separation of locomotives and carriage combinations. As a result no excess carriages have to be transported. Freight trains could therefore be very efficient, with economy of scale and high energy efficiency [1]. However their use can be reduced by lack of flexibility if there is need of transhipment at both ends of the trip due to lack of tracks to the points of pick-up and delivery.

Given the scope of this research, rail container transport is considered an additional service at some locations. In practice are rail and IWT often operating in synchromodal transport. Since the concepts will be designed for small scale applications the throughput volumes are likely not to be substantial enough to justify the construction of kilometres long rail track. If a location for the terminal is under review and rail track is nearby it might be interesting to build a third track so a freight train can stop. Throughput volumes based on rail presence should therefore not be seen as a certainty, but could be assumed to be bonus freight passing over the terminal.

Figure H.1: Example of container train on dedicated freight rail 'Betuwelijn' located between Rotterdam and the German border next to Zevenaar. [Van Vondelen, 2010]

[1] According to the European Environment Agency, CO_2 emissions from rail transport are 3.5 times lower per tonne-kilometre than those from the road transport. [European Court of Auditors, 2016]

H.1.1. Rail vehicles

Movement and carriage of the cargo is performed by two different parts of the train. In contrast to personnel trains having motorized axles on multiple axis along the train, cargo trains are towed by a locomotive being the only driven part. This locomotive delivers the required pulling force for the entire train. Its tractive force hauls the weight of the full train.

Locomotives, as seen on figure H.1, come in two types. There are locomotives that take their fuel/energy internally, diesel powered in most cases, and there are locomotives who use an external power supply. The locomotive in the picture uses electrical energy delivered by the overhead line. A need for external power also means that these trains can only operate on rail tracks with overhead lines. They thus have the need you could say for a double infrastructure, the rails below and the overhead line above. In practise are diesel powered freight trains in minority. Given de duties on diesel, whereas their are none for electricity diesel rail operations are far more expensive than that of electric trains [Van Dorsser, 2015]. Therefore only trains using electricity as power source are under consideration.

Using a locomotive limits the size of a train. The towing power one locomotive can deliver is limited, limiting the load, directly translatable to the number of stack cars, that it can pull. This means that there is a point at which the train needs additional locomotives for sufficient power. Traction between the metal wheels and track is limited, limiting the inclination a track can have.

Considerations worth mentioning are the need for a locomotive. No matter how many wagons are attached, at least one locomotive is required. As a result the trains length is of positive, decreasing effect its costs per wagon, until a second wagon is required. Figure H.2 shows this effect.

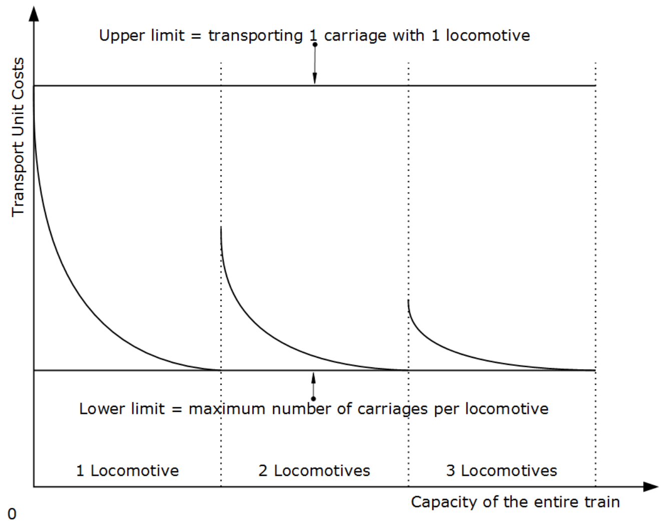


Figure H.2: Development of costs per unit for size increasing locomotive-carriage combinations. (source = own work)

Looking at figure H.1 the containers are stacked one high all in line with the train. Car dimensions set the number and size of containers transportable per car. The carriage size does not really matter for a train as the total combination often consists of several types. Strength wise as in the modes unique selling point, this creates great opportunity for the train as it is easily configured and can be changed pretty easy.

Research by Van der Meulen and Van der Geest [2016] provides insight in costs associated with train transport. The information retrieval and justification process of their data is similar to the explanation provided in Appendix D for IWT. Under the assumption of a train hauling 75 TEU on average, covering an annual distance of 572,520 km in 9,737 hours[2], the train has a cost of €17.19 per km (2015). Since this is for 75 TEU, the average TEU price is 23 cents per km. Per hour these costs are €1011.30 resp. €13.48. These numbers are however for a long-distance rail operation between Rotterdam and Busto Arsizio, Italy based on 260 passes per year and are specific for 2015. Average market cost for the base year 2010 are €14.26 per train km, €0.19 per TEU km, €838.28 per train hour and €11.17 per TEU per hour.

[2] In long distance container freight transport over rail in some cases more than one locomotive is used. Therefore the average likely operational hours per train can be more than 24 times 365 = 8760 hours.

Van Dorsser [2015] shows more realistic figures for the base year 2010. For his research focus was put solely on 45' containers. In this research the focus is put on 20', 40' and 45' containers instead. The train under assumption consists of 33 wagons, with the capacity of loading one 45' container. This is translated to 2 TEU of 1 FEU container. Thus the train has a capacity of 66 TEU. Van Dorsser [2015] proposes an utility slot rate of 80%, having on average 53 TEU on the train. The other wagons are empty and next to the 33 wagons the train is likely to have 7 (20%) extra containers for ease of operation. This provides the rates in table H.1. Between 2010 and 2015 price levels rose, from 119.1 to 143.6, 20.5 percent given market analysis by Panteia [2004]. The 2018 level is deemed 25 percent higher than 2010. The result is a 2018 hour rate of €363.01, which is rounded for convenience to €363.00.

Similar rounding has been applied for the empty 2018 kilometre rate €7.96 which has been rounded to €8.00. The kilometre dependent rates proposed by Van Dorsser for 2010 levels are €7.80 resp. €6.37 for full resp. empty containers.

Table H.1: Cost structure of an electric train (own estimations based on Van Dorsser [2015] and Panteia [2004])

Loading condition	Hour Rate 2010	Hour Rate 2018	Kilometre Rate 2010	Kilometre Rate 2018
Full	€ 290.41	€ 363.00	€ 7.80	€ 9.75
Empty	€ 290.41	€ 363.00	€ 6.37	€ 8.00

Another difference to road and IWT is the control on the modes operations. Whereas a truck driver can pull up the highway and start riding, a train has to follow strict slots, that have to be reserved/purchased. As a result, deciding to haul 30 containers for instance cannot be done at an instance.

Lastly, since rail is relatively fast compared to IWT, it will cover the distance in less time. If no significant volumes are present, the trip interval will be low, leaving a train with many hours of no use. The result being high prices for the periods the train is used.

H.1.2. External Costs

Similar to the approach in subsection 3.1.3 the external costs for rail haulage are determined. External cost factors by rail are similar to IWT with the addition of noise because rail often crosses urban centres. Appendix F explains more with regards to the determination of the exact values. Again the values as based on the work of DG MOVE [2014].

Table H.2: Updated external costs for IWT and base year 2018.

External Cost	3. Air Pollution	4. Noise	5. Climate Change	6. Well-to-tank
Unit measure	€ct/vkm	€/1000vkm	€ct/vkm	€ct/vkm
Value	53.5	1776.5	160.0	229.3

H.1.3. Infrastructure; Rail track and limitations

Figure H.3 shows the Rhine-Alpine rail corridor at which most of the rail freight is carried. Being the backbone of European rail freight transport, this corridor handles the greatest transport volume is carried. Across this corridor 10 inland ports and 100 intermodal terminals are situated of which not all however fall within the scope.

Across Europe track specifications, in particular track width and safety systems differ. Within the region of interest this in not the case, leaving train specifics out of the scope.

Mentioned before, the construction of new railway track is extremely expensive. Projects take many years and millions of Euro's making them not line-up with the scope and goals of this research.

Figure H.3: Rhine-Alpine rail corridor. [Railwaypro, 2017]

Referring back to the need for overhead line for some locomotives, the presence of these lines forms a height restriction. The vast majority of railways enable trains width a certain height, so that stacking of containers can't take place. Important is also that the trains should be able to pass the entire route. On the Dutch 'Betuwe Route', a designated rail track between Rotterdam and the German border near Emmerich, tunnels are prepared for double stacked container transport with overhead lines. With a simple modification to the power supply, the trains could ride in that configuration in no time. From the border deeper into Germany, the Germans however did not prepare for any double stacking in the future. This has made the Dutch investments obsolete, since the distance between Rotterdam and Emmerich is relatively small and mainly intended for transit of cargo.

Width and weight wise limits are already reached, as they are set by the infrastructures capacity. Increasing the length of the trains is now the only real option for improving the capacity, other than laying down more track. Safety systems however have to be updated to facilitate these longer trains. At the moment the EU is undertaking steps to adopt new systems, the ERTMS, so this growth can be facilitated. Adopting this new system however takes decades [Rijksoverheid, retrieved 21/06/2018].

Looking at multiple researches regarding increasing the attractiveness of rail as a way of transport, the other user of the network is brought forward. The main user of rail track within the region of interest is for passenger transport. On freight specific line these do not interfere however most rail is not freight specific. Equal to road transport, the tracks have to be shared. For passenger transport time of departure and arrival are of great importance, leaving the freight trains to be fitted in between. Often these trains have to wait delaying their journey. Freight transport across rail is also set-up differently. A freight train is charged per kilometre of used track, thus leading to a pay-per-use system [European Court of Auditors, 2016]. Road transport demands a tax up front, after which unlimited use of the roads is permitted.

Development wise signs are not all to well for modal-shifting towards rail. The European Court of Auditors performed a study on rail freight transport in the EU. Their conclusion was that the market is still not on the right track. They used the word still, since the EU has been trying to increase its rail freight share actively for over two decades. Mode-share wise they came to the conclusion that rail freight modal share at the EU level has actually declined slightly since 2011 [European Court of Auditors, 2016].

I

Container Details

I.1. Origin of the container and its current specifications

Starting with the origin of the container, the situation before the container's existence is interesting. Before, goods were transported as break bulk cargo. This means that typically goods would be loaded to and from vehicles in smaller parcels. This could be in bags, pallets or bales. When the vehicles, being a truck, train or boat, needed to be (un)loaded, many dockworkers were needed to perform this cargo handling. As a result, transhipment of cargo took a long time and required a great number of dockworkers, leading to high transhipment costs.

Halfway in previous century, several container concepts had been designed and some even being used. As with the development of new method, many diverse types try to become market leading, yet in the end only one is adopted. The container as used now finds its roots in 1955, when Malcom McLean and Keith Tantlinger came up with a concept, being a steel box of 8 feet (2.4m) tall, 8 feet wide and 10 feet (3.0m) long [McGough et al., 2010]. This concept contained a twistlock and casting mechanism at each corner, enabling easy handling of the container.

Developments in handling equipment lead to the increase in container dimensions. In turn the real common container measurement came forward, being the Twenty-foot Equivalent Unit. This is now referred to as a TEU.

(a) Example of Open Top container [Hapag-Lloyd AG, 2016]

(b) Example of a Flatrack container [Hapag-Lloyd AG, 2016]

(c) Example of a Reefer container [FUWA, retrieved 28/02/2018]

(d) Example of a Tank container [C Rail Intermodal, retrieved 28/02/2018]

Figure I.1: Overview of four special container types.

J
Inland Terminal Cost Characteristics

Inland terminal cost structures and their resulting cost levels have been researched by many. Two researches have made estimations for comparable terminal sizes at relatively the same period. The first two table are from Smid et al. [2016]. Table J.3 is by Wiegmans and Konings [2015]. For this research are the small and medium sized terminals of particular interest because they form the current market, future competition and the basis for estimation required for the terminal concepts. The larger terminals are of secondary interest and give insight in the effect of scale for terminal costs.

It is important to keep in mind that the numbers provided by both researches contain estimations of their own, meaning that they are not necessarily accurate or a true market representation. Suppliers and reviewers have cooperated with the authors for the papers, making the number more accurate. They do however provide insight in the relative cost contributions and the order of size for several different cost factors.

Table J.1: Terminal characteristics for variable inland container terminal sizes (Base year = 2015). [Smid, Dekker, and Wiegmans, 2016]

Characteristics	Small 20,000	Medium 50,000	Large 125,000	XL 200,000	XXL 500,000
Area	1.5 ha	3 ha	3 ha	7 ha	20 ha
Quay(s)	200 m	200 m	240 m	300 m	400 m
Crane	1	1	2	2	3
Other equipment (reach stackers)	1	1	2	3	2
Office	Shed, 100 m^2	Shed, 100 m^2	Shed, 100 m^2	Shed, 100 m^2	Shed, 100 m^2
IT systems	Fixed amount	Fixed amount	Fixed amount	Fixed amount	Fixed amount
Fence	370 m	490 m	500 m	750 m	1300 m
Lighting poles	4	8	12	36	72
Interest	4% of total assets	4% of total assets	4% of total assets	4% of total assets	4% of total assets
Insurance	25,000	50,000	50,000	50,000	50,000
Licenses	50,000	50,000	50,000	50,000	50,000
Other	5% of fixed costs	5% of fixed costs	5% of fixed costs	5% of fixed costs	5% of fixed costs
Employees	4 fte	8 fte	12 fte	24 fte	48 fte
Manager	1.0 fte	1.5 fte	3.0 fte	5.0 fte	10.0 fte
Guards	2 persons	2 persons	2 persons	2 persons	2 persons
Fuel	Diesel (hl)	Diesel (hl)	Diesel (hl)	Diesel (hl)	Diesel (hl)
Electricity	kW h	kW h	kW h	kW h	kW h
Repair and maintenance	5% of assets	5% of assets	5% of assets	5% of assets	5% of assets
Operating hours/day	11	13	15	16	24
Operating days/week	5	5	5	5	7
Import/export balance	50–50	50–50	50–50	50–50	50–50

Table J.2: Terminal cost structure for variable inland container terminal sizes. (Base year = 2015) [Smid, Dekker, and Wiegmans, 2016]

	S (%)	S (€)	M (%)	M (€)	L (%)	L (€)	XL (%)	XL (€)	XXL (%)	XXL (€)
Fixed costs										
Area	9	€132.000	12	€264.000	7	€264.000	11	€616.000	15	€1.760.000
Quay(s)	2	€25.000	1	€25.000	1	€30.000	1	€37.500	0	€50.000
Crane	20	€276.000	13	€276.000	18	€646.000	13	€740.000	8	€1.016.000
Reach stackers	3	€40.000	2	€50.000	2	€80.000	2	€120.000	1	€80.000
Office	1	€10.000	0	€10.000	0	€10.000	0	€10.000	0	€10.000
IT systems	5	€66.667	5	€100.000	3	€100.000	2	€100.000	1	€100.000
Fence	0	€3.145	0	€4.165	0	€4.250	0	€6.375	0	€11.050
Lighting poles	0	€624	0	€1.248	0	€1.872	0	€5.616	0	€11.232
Interest	19	€263.383	17	€377.516	15	€541.674	15	€884.473	16	€1.907.066
Insurance	2	€25.000	2	€50.000	1	€50.000	1	€50.000	0	€50.000
Terminal taxes (licenses)	4	€50.000	2	€50.000	1	€50.000	1	€50.000	0	€50.000
Other	3	€44.591	3	€60.396	2	€88.890	2	€130.998	2	€252.267
Semi variable costs										
Employees	14	€200.000	18	€400.000	16	€600.000	21	€1.200.000	20	€2.400.000
Management fee	7	€100.000	7	€150.000	8	€300.000	9	€500.000	8	€1.000.000
Guards	0	€5.000	0	€5.000	0	€5.000	0	€5.000	0	€5.000
Variable costs										
Fuel/electricity	9	€130.000	15	€325.000	22	€810.000	22	€1.300.000	27	€3.250.000
Repair and maintenance	2	€27.672	2	€36.521	2	€56.806	1	€81.775	1	€151.914
Total	100	€1.399.081	100	€2.184.846	100	€3.638.492	100	€5.837.737	100	€12.104.530

Table J.3: Cost build-up specifications for five different, currently existing types of inland container terminals (Base year = 2011). [Wiegmans and Konings, 2015]

	measure	Small	Small (low profile)	Medium	Large	Very large
Terminal profile						
Handling capacity	containers/ year	20.000	20.000	50.000	125.000	200.000
Terminal equipment	units	1 MS 1 RS	1 MS* 1 FL	1 MS 1 RS	1 PC 1 MC 2 RS	2 PC 3 RC
Surface	ha	1,5	0,75	3	3	7
Quay length	meters	200	100	200	240	300
Fixed costs:						
Land	€ / year	88.000	66.000	200.000	264.000	616.000
Quay	€ / year	75.000	37.500	75.000	90.000	113.000
Equipment (cranes + transport)		163.000	29.700	163.000	373.000	445.000
Labor costs	€ / year	200.000	200.000	400.000	600.000	1.200.000
Interest		272.000	272.000	368.000	598.000	957.000
Variable costs:						
Fuel costs (diesel + electricity)		100.000	100.000	150.000	300.000	600.000
Repair and maintenance costs		22.000	12.000	28.000	42.000	65.000
Office	€ / year	10.000	10.000	10.000	10.000	10.000
ICT	€ / year	100.000	100.000	100.000	100.000	100.000
Other costs	€ / year	83.000	83.000	110.000	111.000	118.000
Other	€ / year	22.000	12.000	28.000	42.000	65.000
Management fee		100.000	50.000	150.000	300.000	500.000
TRANSHIPMENT COST						
Cost at 60% terminal utilization	€ / handling	103	81	60	38	40
Cost at 80% terminal utilization	€ / handling	77	61	45	28	30
Cost at 100% terminal utilization	€ / handling	62	49	36	23	24

MS: mobile crane, RS: reachstacker, PC: portal crane,
MS*: second hand mobile crane, FL: forklift (18 tonne)
The other indirect costs include lighting, security (guards and fences), insurance, terminals taxes (licenses).

K

Additional Information regarding the Rules and Regulations for Inland Terminals

The location of the terminal is of influence on the applicable rules. The Dutch waterway administrator, Rijkswaterstaat [2017a], has written a set of rules regarding inland ports and waterways. They make a clear distinction between wharves[1] and harbours for inland navigation. They state that:

On larger waterways, i.e. those with more than 30,000 commercial vessel movements a year, and along waterways in class V or higher, bankside quays and wharves should be avoided as much as possible, and docks constructed instead. This rule does not apply to very wide waterways where no obstructive water movement is expected.

On normal and quiet waterways, a reference vessel moored at a wharf must be situated entirely outside the contiguous shoreline. The embankment must be recessed at least as far as the beam of the reference vessel, so that vessels passing through are not obstructed by speed restrictions, plus a safety zone S whose size is equal to the value given in table 29.

The greater the distance over which a waterway is flanked by quays and wharves, the less suitable it will be for through traffic. Quays and wharves should be grouped as far as possible in order to prevent speed restrictions from being imposed over long distances, which has a negative impact on overall journey speed. The distance between harbours and/or wharves must be no less than approx. one hour's travelling time. In other words: 10 km on waterways in class III or lower, and 15 km on waterways in class IV and above. Local conditions may however justify deviation from this rule.

The actual shoreline must remain visible for shipping despite the presence of wharves. The number of wharves already present will therefore be a factor in the decision as to whether construction of a new wharf is acceptable.

A sudden change in the dimensions of a canal's cross-section, at a wharf for example, can cause controllability problems. The transition in the horizontal plane from a wharf to the waterway must therefore be gradual, at least 1:2. The depth of a wharf must be the same as that of the waterway. The length of the wharf must be at least 1.1.L, where L is the length of the reference vessel. Where there is a single fixed crane or hopper, the length must be 2.L so that vessels can move from one mooring to another. [Rijkswaterstaat, 2017a]

One of the things of interest is seen in the citations last paragraph. That when there is a single fixed crane or hopper, the required quay length has to be increased significantly. This rule is however based on the need for vessel to move during (un)loading. For the concepts this is an important notice. When there has to be made a new quay, significant costs have to be made. Especially when multiple terminals have to developed along a waterway. Rules are however subject to change. When Rijkswaterstaat can be convinced a new concepts requires a safe change or the rules this may be regarded as plausible. The concepts will incorporate both versions that hold the possibility of self-moving the containers and a version that should move along the quay wall.

[1]Warves are parallel moorings situated alongside the waterway itself. [Rijkswaterstaat, 2017a]

The same consideration counts for docks and recessed harbours. On smaller waterways these are not necessarily required, yet the wharves may not reduce the effective waterways width. When such recesses have to be dug, significant costs are encountered.

Looking more at the process or berthing and de-berthing. At a wharve mooring is easy and quick as no difficult and time consuming movements have to be conducted for berthing. Turning might be considered difficult as the next citation will show. At a recessed harbours, manoeuvring becomes more difficult. This can cost significant time and additional risk. Rijkswaterstaat does prescribe rules in relation to manoeuvring and the design around terminals, wharves and docks.

Turning at wharves

A wharf should in principle have a place where vessels can turn, either a dock or turning basin. Vessels generally return in the direction from which they came and therefore have to turn around. The turning facility must be an acceptable distance from the wharf and, depending on how much traffic there is, it should be possible to reach it travelling forward.

It is only acceptable for vessels to have to travel backwards to a turning facility by way of an exception, and if it does not obstruct other shipping. The distance that the vessel is required to travel backwards may not exceed 1000 m. These rules may be applied with a certain amount of flexibility on canals with a low volume of traffic.

Turning in harbours

It is desirable for harbours that are over 1000 m long, or over 10 times the length of the reference vessel, to have a turning facility at the end. If it is difficult to provide a separate turning basin, if fewer than 30,000 cargo vessels a year pass on the main waterway, and if the harbour is perpendicular or virtually perpendicular to the waterway, then the space where the harbour joins the waterway can be used. The junction must be in the form of a T. At the point where vessels turn, any vertical banks that it may collide with must have contiguous coping along the top to prevent damage from overhangingships' bows.

Diameter of turning basin

A turning basin is a circular widening of the waterway or harbour where vessels can turn. The circle has a diameter of 1.2.L (L = length of reference vessel). Within this circle, the depth should be the same as that of the waterway or harbour. In all cases, measures should be taken to protect the bank from extra erosion due to the eddies caused by propellers.

Rules and regulations such as presented in the past citation are written to ensure safe navigation on inland waterways. In practise can these rules limit the options for locating terminals near small inland waterways. Limitations as this bring costs along. Either the terminal has to be located at a less than ideal location, reducing its attractiveness and potential effectiveness. Another solution might require changes in current infrastructure, bringing significant cost along.

These highlights are a selection of the set of rules and regulations provided by Rijkswaterstaat [2017a]. For the other countries within the Blue Corridor similar sets of requirements are applicable. It is to cumbersome and irrelevant to analyse all these individual cases in an attempt to have a solution that is (near) perfect in all possible configurations. As a result these rules are shown here for informative purpose, meaning that rules and regulations such as these also do play a role when assessing a terminal concept.

L

(Bunker) Oil Price Developments

L.1. Bunker price development throughout the year

Crude oil prices vary from day to day due to global trade changes. For the bunker fuel prices similar changes do apply, yet less volatile on a day to day basis. What is however changing is the average asking price per month. This can be caused by mid term crude oil price changes, but is also a result of the current market conditions. Bunker station owners know the market and whether ship owners are making good margins or not.

In periods of low cargo rates, shippers are under pressure, therefore limiting their fuel use. Bunker facilitators notice this and lower their prices to keep attracting customers. In periods of high freight prices, the ship owner is making good money on the operations. It is at this time that bunker prices will be raised, so that bunker station owners can lift on this period of good margins.

On average the bunker fuel was sold at €332 per 1000 litres or €0.33 per litre. Ziel [2017] provided a forecast of 40 cents per litre based on his table shown below. Since his work, crude oil has risen from $43.55 (2016 average) to $66.81 for the 2018 running average. It is therefore that this research does not follow the forecast of Ziel.

For the approximately 50 percent increase in fuel cost and increased trade across the Blue Corridor, bunker prices have already risen to 0.63 cent per litre[1]. For this report, given that May and June were just above average in the 2016 cycle, the average fuel price is at 60 cent per litre at a crude oil price of $68 per barrel WTI and $73 for Brent Crude[2].

Table L.1: Bunker price development over the year 2016. [Ziel, 2017]

Average price for 1000 litre duty and tax free gasoline in 2016 = €332							
January	€255.00	April	€300.00	July	€335.00	October	€370.00
February	€255.00	May	€345.00	August	€335.00	November	€370.00
March	€295.00	June	€365.00	September	€340.00	December	€420.00
Q1 average	€268.33	Q2 average	€336.67	Q3 average	€336.67	Q4 average	€386.67

[1] The CBRB, Central Bureau voor de Rijn- en Binnenvaart, publishes a continues indicator for gasoline. The fuel price is an average across the inland waterway network of Europe. It is however limited to members-only view. Contargo, a inland container market leader, shows monthly average prices of this index on its website. [Contargo, retrieved table for June 2018 on 03/05/2018]

[2] Retrieved from Bloomberg.com/energy at 03/05/2018

L.2. Crude Oil prices both historical an forecast

The primary driver for variable cost is the price a ship owner has to pay for it fuel supply. These bunker costs are in a direct link with crude oil prices, yet somewhat delayed. The fuel a bunker stations sells today has seen its crude oil transaction period some time ago, before the refining process took place.

Changes in the crude price come from both the supply and demand side. With global uncertainty about the stability of some oil producing regions, supply might become scarce, driving up the prices.

In case global trade disappoints, the demand for products such as oil will decline, lowering the price one is willing to pay for oil.

Over the past decade crude oil has been on a volatile, yet upwards trend as figure L.1 shows. Even after the sharp decline in Q4 of 2014, the lowest level was higher than any seen in previous era for a substantial time. With the increased volatility, especially since 2000, the forecasts for futures have also become less certain. The three shown forecasts in the figure show how the market was expected to behave and that it did not follow that forecast.

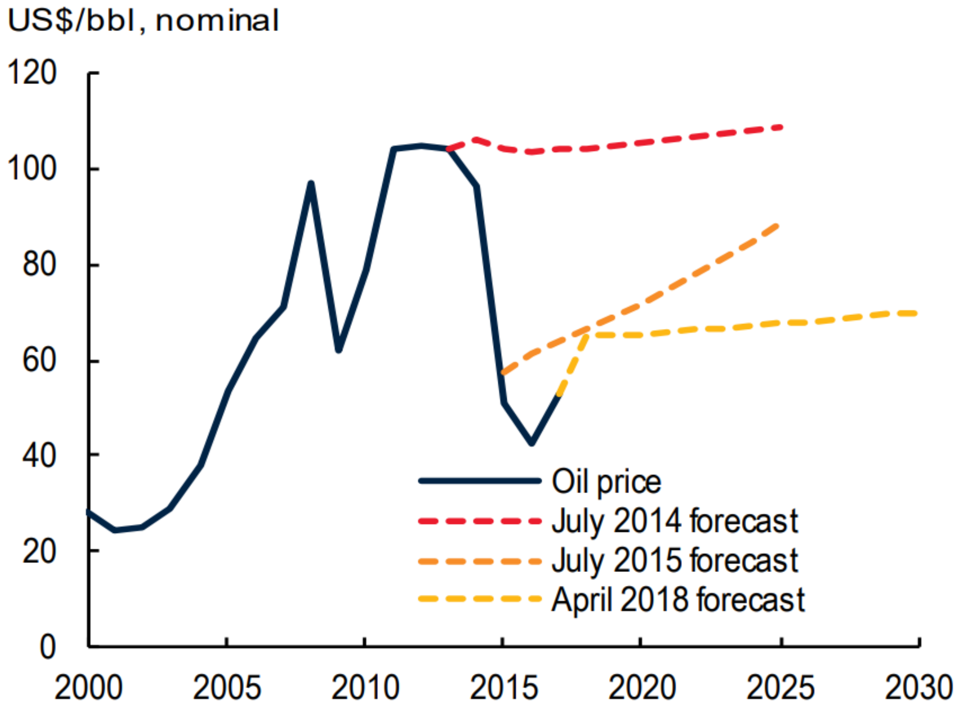
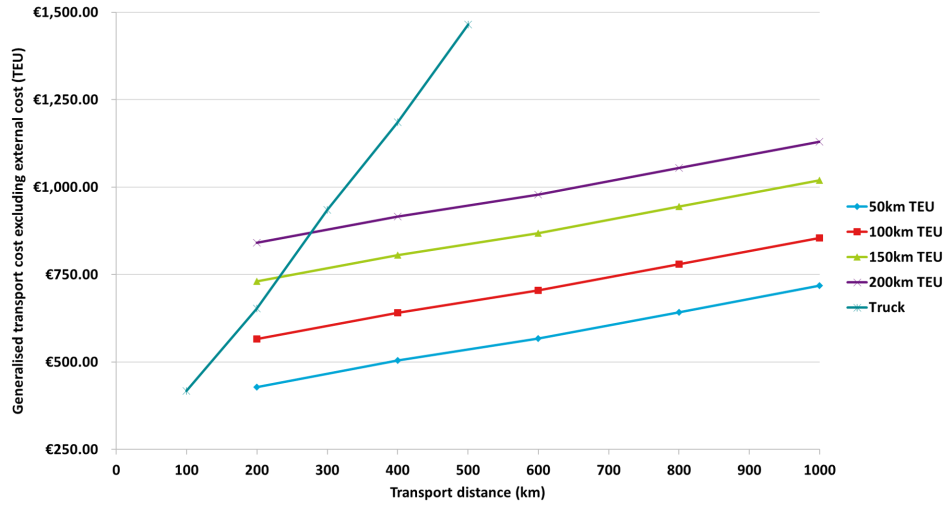


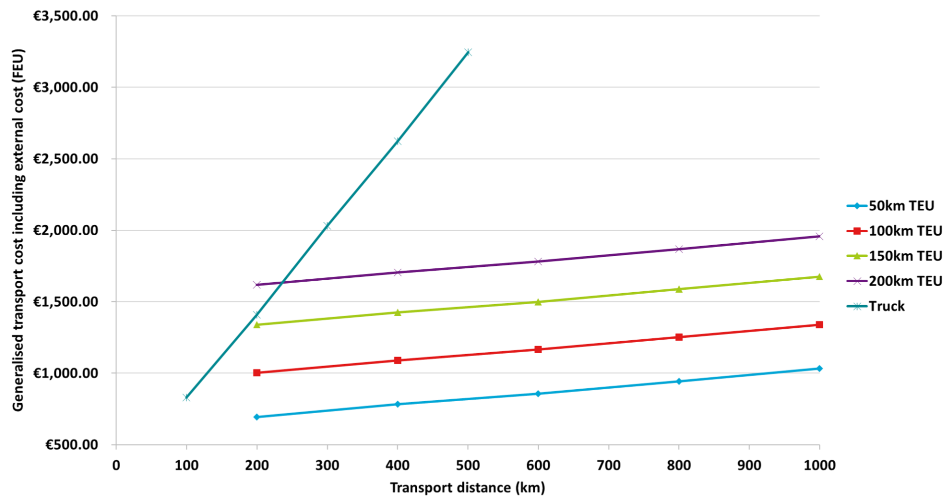
Figure L.1: Crude oil price both history and forecast. [World Bank Group, 2018]

M

Generalized Cost Breakdown of Competitor Container Service Costs

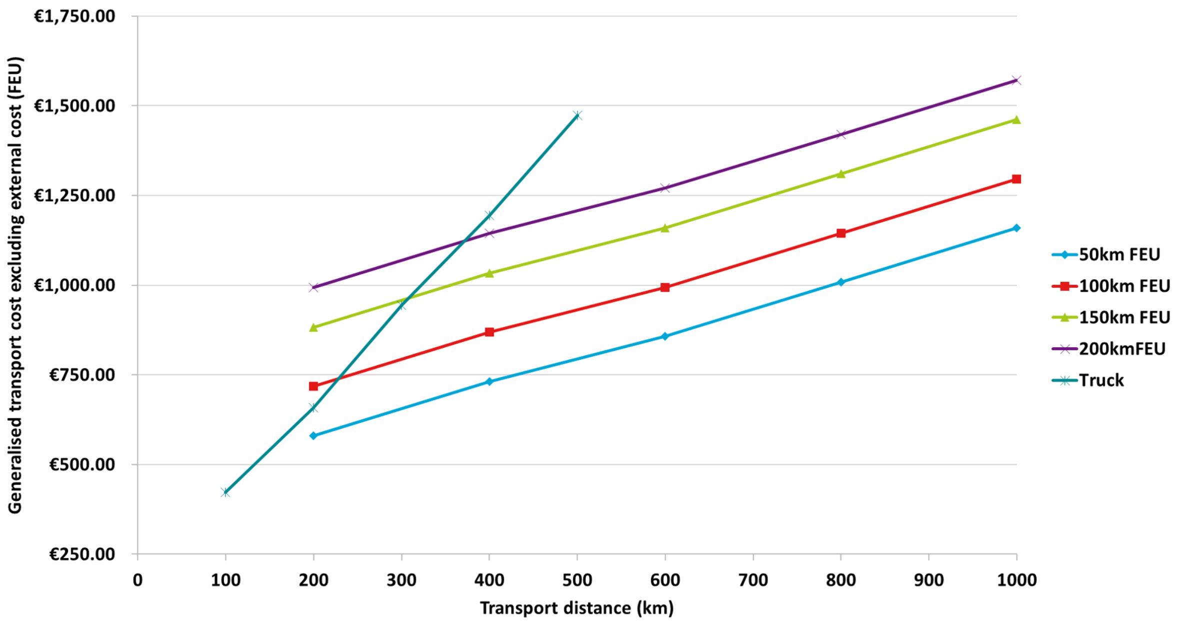


(a) CEMT Va GC (excl. ec) for a TEU.

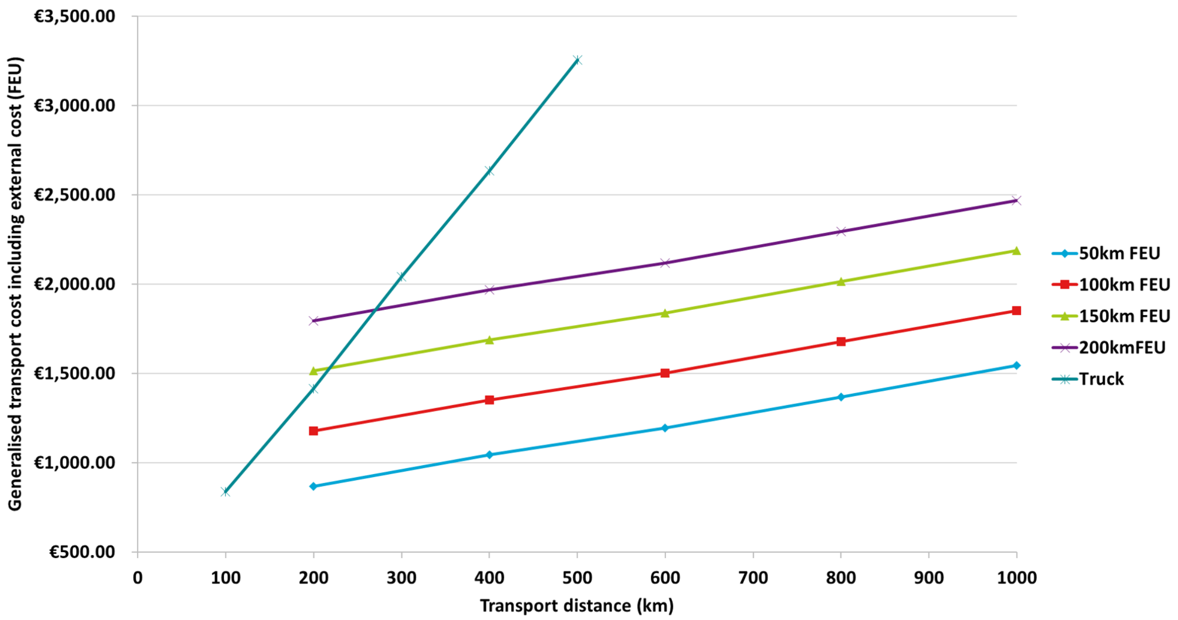


(b) CEMT Va GC (incl. ec) for a TEU.

Figure M.1: CEMT Va competition for transporting a TEU container



(a) CEMT Va GC (excl. ec) for a FEU.



(b) CEMT Va GC (incl. ec) for a FEU.

Figure M.2: CEMT Va competition for transporting a FEU container

Table M.1: Background values for TEU related cost of the CEMT Va barge alternative. Numbers relate to section 6.1

	Sailing Distance (km)	PPH Distance (km) 50	100	150	200		Sailing Distance (km)	PPH Distance (km) 50	100	150	200
O.o.p.	200	€369.43	€506.31	€669.93	€780.06	R&R	200	€24.49	€24.49	€24.49	€24.49
	400	€415.59	€552.46	€716.09	€826.21		400	€41.29	€41.29	€41.29	€41.29
	600	€461.74	€598.62	€762.24	€872.37		600	€58.09	€58.09	€58.09	€58.09
	800	€507.89	€644.77	€808.39	€918.52		800	€74.89	€74.89	€74.89	€74.89
	1000	€554.05	€690.92	€854.55	€964.67		1000	€91.69	€91.69	€91.69	€91.69
	Sailing Distance (km)	50	100	150	200		Sailing Distance (km)	50	100	150	200
Time	200	€34.94	€34.94	€35.94	€35.94	EC	200	€265.57	€436.42	€607.27	€778.12
	400	€47.41	€47.41	€48.41	€48.41		400	€277.72	€448.56	€619.41	€790.26
	600	€47.41	€47.41	€48.41	€48.41		600	€289.86	€460.71	€631.55	€802.40
	800	€59.88	€59.88	€60.88	€60.88		800	€302.00	€472.85	€643.70	€814.55
	1000	€72.35	€72.35	€73.35	€73.35		1000	€314.15	€484.99	€655.84	€826.69
	Sailing Distance (km)	50	100	150	200		Sailing Distance (km)	50	100	150	200
GC (excl.)	200	€428.87	€565.74	€730.37	€840.49	GC (incl.)	200	€694.44	€1,002.16	€1,337.63	€1,618.61
	400	€504.29	€641.16	€805.79	€915.91		400	€782.01	€1,089.73	€1,425.20	€1,706.17
	600	€567.24	€704.12	€868.74	€978.87		600	€857.10	€1,164.82	€1,500.30	€1,781.27
	800	€642.67	€779.54	€944.17	€1,054.29		800	€944.67	€1,252.39	€1,587.86	€1,868.84
	1000	€718.09	€854.97	€1,019.59	€1,129.72		1000	€1,032.24	€1,339.96	€1,675.43	€1,956.40

Table M.2: Background values for FEU related cost of the CEMT Va barge alternative. Numbers relate to section 6.1

	Sailing Distance (km)	PPH Distance (km) 50	100	150	200		Sailing Distance (km)	PPH Distance (km) 50	100	150	200
O.o.p.	200	€461.74	€598.62	€762.24	€872.37	R&R	200	€48.98	€48.98	€48.98	€48.98
	400	€554.05	€690.92	€854.55	€964.67		400	€82.58	€82.58	€82.58	€82.58
	600	€646.36	€783.23	€946.86	€1,056.98		600	€116.18	€116.18	€116.18	€116.18
	800	€738.66	€875.54	€1,039.16	€1,149.29		800	€149.78	€149.78	€149.78	€149.78
	1000	€830.97	€967.85	€1,131.47	€1,241.60		1000	€183.38	€183.38	€183.38	€183.38
	Sailing Distance (km)	50	100	150	200		Sailing Distance (km)	50	100	150	200
Time	200	€69.88	€69.88	€71.88	€71.88	EC	200	€287.72	€458.56	€629.41	€800.26
	400	€94.82	€94.82	€96.82	€96.82		400	€312.00	€482.85	€653.70	€824.55
	600	€94.82	€94.82	€96.82	€96.82		600	€336.29	€507.14	€677.98	€848.83
	800	€119.76	€119.76	€121.76	€121.76		800	€360.58	€531.42	€702.27	€873.12
	1000	€144.70	€144.70	€146.70	€146.70		1000	€384.86	€555.71	€726.56	€897.40
	Sailing Distance (km)	50	100	150	200		Sailing Distance (km)	50	100	150	200
GC (excl.)	200	€580.61	€717.48	€883.11	€993.23	GC (incl.)	200	€868.32	€1,176.04	€1,512.52	€1,793.49
	400	€731.45	€868.33	€1,033.95	€1,144.08		400	€1,043.46	€1,351.18	€1,687.65	€1,968.62
	600	€857.36	€994.24	€1,159.86	€1,269.99		600	€1,193.65	€1,501.37	€1,837.84	€2,118.82
	800	€1,008.21	€1,145.08	€1,310.71	€1,420.83		800	€1,368.78	€1,676.51	€2,012.98	€2,293.95
	1000	€1,159.06	€1,295.93	€1,461.56	€1,571.68		1000	€1,543.92	€1,851.64	€2,188.11	€2,469.09

Table M.3: Background values for average box related cost of the CEMT Va barge alternative. Numbers relate to section 6.1

		PPH Distance (km)						PPH Distance (km)			
	Sailing Distance (km)	50	100	150	200		Sailing Distance (km)	50	100	150	200
O.o.p.	200	€429.43	€566.31	€729.93	€840.06	R&R	200	€40.41	€40.41	€40.41	€40.41
	400	€505.59	€642.46	€806.09	€916.21		400	€68.13	€68.13	€68.13	€68.13
	600	€581.74	€718.62	€882.24	€992.37		600	€95.85	€95.85	€95.85	€95.85
	800	€657.89	€794.77	€958.39	€1,068.52		800	€123.57	€123.57	€123.57	€123.57
	1000	€734.05	€870.92	€1,034.55	€1,144.67		1000	€151.29	€151.29	€151.29	€151.29
	Sailing Distance (km)	50	100	150	200		Sailing Distance (km)	50	100	150	200
Time	200	€57.65	€57.65	€59.30	€59.30	EC	200	€279.97	€450.81	€621.66	€792.51
	400	€78.23	€78.23	€79.88	€79.88		400	€300.00	€470.85	€641.70	€812.55
	600	€78.23	€78.23	€79.88	€79.88		600	€320.04	€490.89	€661.73	€832.58
	800	€98.80	€98.80	€100.45	€100.45		800	€340.08	€510.92	€681.77	€852.62
	1000	€119.38	€119.38	€121.03	€121.03		1000	€360.11	€530.96	€701.81	€872.65
	Sailing Distance (km)	50	100	150	200		Sailing Distance (km)	50	100	150	200
GC (excl.)	200	€527.50	€664.37	€829.65	€939.77	GC (incl.)	200	€807.46	€1,115.18	€1,451.31	€1,732.28
	400	€651.95	€788.82	€954.10	€1,064.22		400	€951.95	€1,259.67	€1,595.79	€1,876.77
	600	€755.82	€892.69	€1,057.97	€1,168.09		600	€1,075.86	€1,383.58	€1,719.70	€2,000.68
	800	€880.27	€1,017.14	€1,182.42	€1,292.54		800	€1,220.34	€1,528.07	€1,864.19	€2,145.16
	1000	€1,004.72	€1,141.59	€1,306.87	€1,416.99		1000	€1,364.83	€1,672.55	€2,008.67	€2,289.65

Table M.4: Costs for TEU transport by truck

Truck Distance (km)	100	200	300	400	500
O.o.p.	€380.75	€616.65	€896.10	€1,146.68	€1,426.13
Time	€6.25	€6.25	€8.50	€8.50	€8.50
R&R	€30.00	€30.00	€30.00	€30.00	€30.00
EC	€414.28	€755.97	€1,097.67	€1,439.36	€1,781.06
GC (excl.)	€417.00	€652.90	€934.60	€1,185.18	€1,464.63
GC (incl.)	€831.28	€1,408.87	€2,032.27	€2,624.54	€3,245.68

Table M.5: Costs for FEU transport by truck

Truck Distance (km)	100	200	300	400	500
O.o.p.	€380.75	€616.65	€896.10	€1,146.68	€1,426.13
Time	€12.50	€12.50	€17.00	€17.00	€17.00
R&R	€30.00	€30.00	€30.00	€30.00	€30.00
EC	€414.28	€755.97	€1,097.67	€1,439.36	€1,781.06
GC (excl.)	€423.25	€659.15	€943.10	€1,193.68	€1,473.13
GC (incl.)	€837.53	€1,415.12	€2,040.77	€2,633.04	€3,254.18

Table M.6: Costs for average container transport by truck

Truck Distance (km)	100	200	300	400	500
O.o.p.	€380.75	€616.65	€896.10	€1,146.68	€1,426.13
Time	€10.31	€10.31	€14.03	€14.03	€14.03
R&R	€30.00	€30.00	€30.00	€30.00	€30.00
EC	€414.28	€755.97	€1,097.67	€1,439.36	€1,781.06
GC (excl.)	€421.06	€656.96	€940.13	€1,190.70	€1,470.15
GC (incl.)	€835.34	€1,412.94	€2,037.79	€2,630.06	€3,251.21

N

Stability of the SCCC

Subsection 7.2.1 contained the assumed values for the SCCC's hull width or breadth. These assumptions are vital for the use of the SCCC compared to existing inland vessels of sub-optimal width. To verify the assumptions a first stability iteration has been made. Mentioned in chapter 7 are the *'22ZZ'* en *'23ZZ'* currently sailed with in the form of the Neokemp and Neokemp*. It is thereby assumed that these will hold sufficient stability.

For the *'3YZZ'* models it is known that for 2 layers of height (Y=2) always sufficient stability is achieved [CCR EBU ESO Aquapol, 2015]. As soon as the number of container stacked equals or surpasses the width of the stack stability becomes critical. It was for this reason 200t of ballast was proposed for the *'33ZZ'* and 500t for the *'34ZZ'*.

For a stability perspective there is one primary indicator. The GM-value is the distance between the ship's (incl. cargo) gravitational point G and the metacentre M. The stability rules demand GM to be at least 1.00 metres in case of unsecured containers (no lashing, stack cones, twistlocks and/or cell guides) (6.1.4 Art. 22.02) and at least 0.50 metres for secured containers (6.1.5 Art. 22.03) [CESNI, 2015].

To calculate this stability indicator equation N is used. The equation shows the additional characters K (Keel) and B (Buoyancy point). The momentum arm KB describes the self-righting capacity of the vessel whereas KG contains the heeling capacity. Figure N.1a does show where these points lie in a basic ship. To be able to relatively easily do computations for the SCCC a more basic hull form is proposed. Figure N.1b does show the three cases of interest.

$$GM = KB + BM - KG \tag{N.1}$$

$$GM = \frac{1}{2} * Draught + \frac{I_t}{\nabla} - height of the gravity point. \tag{N.2}$$

The grey bullet is the gravitational point of the hull. The black bullets are the gravity point of each loaded container and are located at approximately 35% of the container height. For empty container the gravity point is located halfway the container's height. Together the weights and gravity points determine the overall location of G and thereby KG.

Buoyancy point B is located at half the draught.

For an assumed square mainframe the cross plane moment of inertia I_t is equal to the volume of displaced water times the distance over which this takes place. Results being that for a mainframe of length 1 (no unit required) the I_t follows from equation N. The displaced volume ∇ is calculated via equation N.

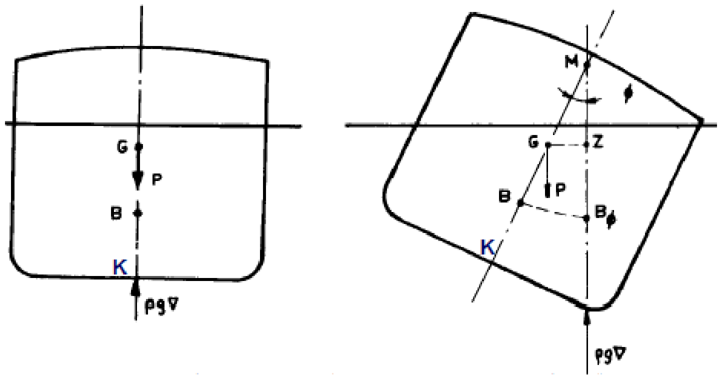
$$I_t = \frac{1}{12} \cdot B^3 \cdot L = \frac{1}{12} \cdot (9.3 \text{ or } 9.5)^3 \cdot 1 \tag{N.3}$$

$$\nabla = L \cdot B \cdot T = 1 \cdot 9.3 \text{ or } 9.5 \cdot 2.5 \text{ or } 3.0 \tag{N.4}$$

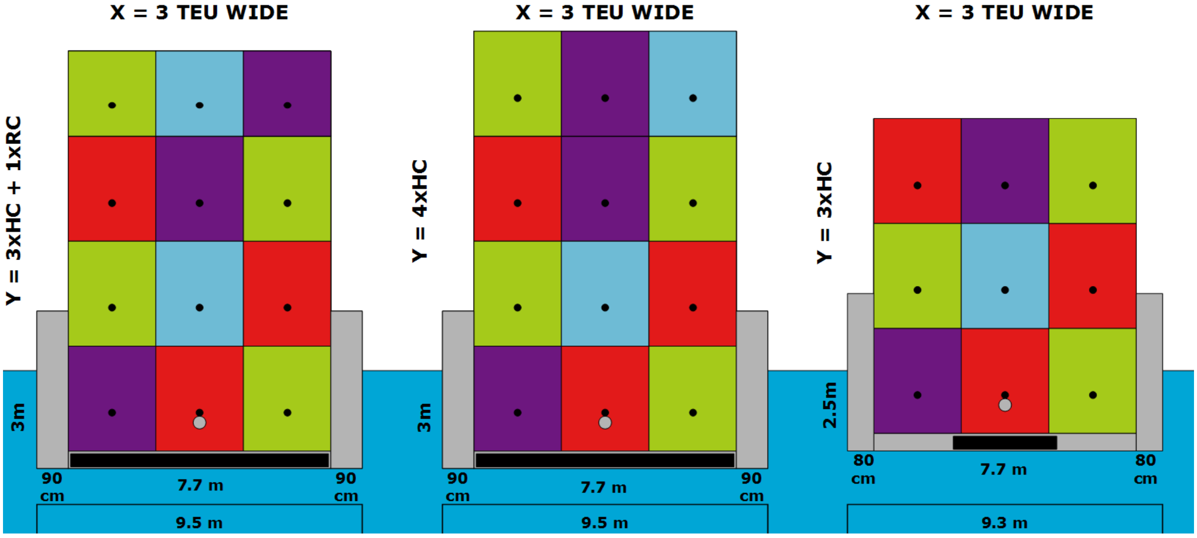
Table N.1: Stability calculation results

SCCC type		33ZZ	34ZZ	34ZZ	34ZZ	34ZZ
Loading condition		3 layers HC all loaded	4 layers HC all loaded	4 layers RC all loaded	2L HC + 2L RC lower 3 loaded upper empty	2L HC + 2L RC lower 3 loaded upper empty
KB		1.25m	1.50m	1.50m	1.50m	1.50m
Breadth		9.3m	9.5m	9.5m	9.5m	9.5m
	I_t	67.03m^4	71.48m^4	71.48m^4	71.48m^4	71.48m^4
	∇	23.25m^3	28.50m^3	28.50m^3	28.50m^3	28.50m^3
BM		2.88m	2.51m	2.51m	2.51m	2.51m
Hull	Weight	5.1t	5.4t	5.4t	5.4t	5.4t
	Z_hull	1.4m	1.4m	1.4m	1.4m	1.4m
Ballast	Weight	2t	5t	5t	5t	5t
	$Z_ballast$	0.10m	0.25m	0.25m	0.25m	0.25m
1^{st} Tier	Weight L1	7.4t	7.4t	7.4t	7.4t	7.4t
	Z_L1	1.5m	1.5m	1.4m	1.5m	1.4m
2^{nd} Tier	Weight L2	7.4t	7.4t	7.4t	7.4t	7.4t
	Z_L1	4.4m	4.4m	4.0m	4.4m	4.1m
3^{th} Tier	Weight L3	7.4t	7.4t	7.4t	7.4t	7.4t
	Z_L1	7.3m	7.3m	6.6m	7.2m	7.0m
4^{th} Tier	Weight L4	-	7.4t	7.4t	1.2t	1.2t
	Z_L1	-	10.2m	9.2m	10.2m	10.2m
	Weight sum	29.3t	40t	40t	33.8t	33.8t
KG	$Z_average$	3.58m	4.55m	4.14m	3.49m	3.36m
GM		0.55m	-0.54m	-0.13m	0.52	0.65m

The resulting GM values in table N.1 underwrite the sensitivity of inland container vessels. The *'33ZZ'* series meets the GM ≥ 0.50m following the rules. The fully loaded *'34ZZ'* either fully loaded with loaded HC's or RC's (regular container) have negative upright stability and do not meet the minimum required rules. A more realistic case of loading two layers of full HC's on the bottom, adding a third layer of full RC's and a fourth of empty RC's has a GM of 0.52 metres. Enough but only barely. By having the HC's at the bottom all upper container's points of gravity are lifted. Last column contains the same load but now by having 1 layer of full RC's at the bottom, 2 tiers of HC's and empty RC's as fourth layer. This lowers the average gravity point of the load and thereby lowers the gravitational location of the overall vessel. The result is a higher and more respectable value for GM.



(a) Overview of stability defining point locations and the directions of forces. [Keuning, 2013]



(b) Overview of loading condition and location or several points of gravity. Also shown are hull dimensions and the centre of buoyancy (grey dot). [source = (own work)]

Figure N.1: Drawings used to perform calculations regarding the SCCC's upright, still water stability.

O

SCCC: Constants Used for Estimation Algorithms

Table O.1: Steel weight - coefficients for transversely framed container vessels. [Hekkenberg, 2013]

	Unstandardized Coefficients		Standardized Coefficients		
	Value	Std. Error	Beta	t	Sig.
c1	-2.20E+01	12.848		-1.713	0.087
c2	2.54E-01	1.03E-02	0.317	24.658	0
c3	-1.98E-03	4.07E-04	-0.086	-4.851	0
c4	4.47E-02	3.02E-03	0.194	14.803	0
c5	1.06E-06	2.11E-08	0.593	50.218	0
c6	9.60E-01	0.149	0.058	6.43	0
c7	6.68E+02	454.349	0.007	1.469	0.142

Table O.2: Piping weight - coefficients for dry bulk vessels. [Hekkenberg, 2013]

	Unstandardized Coefficients		Standardized Coefficients		
	Value	Std. Error	Beta	t	Sig.
c1	-2.72E+00	9.06E-02		-30.036	0
c2	6.23E-02	4.49E-04	0.843	138.706	0
c3	5.05E-02	3.73E-03	0.089	13.529	0
c4	9.97E-02	1.66E-02	0.034	5.994	0
c5	1.34E-04	9.09E-06	0.153	14.786	0

Table O.3: Machinery, equipment and outfitting weight - coefficients for dry bulk vessels. [Hekkenberg, 2013]

	Unstandardized Coefficients		Standardized Coefficients		
	Value	Std. Error	Beta	t	Sig.
c1	2.80E+01	1.39E+00	20.197	0	
c2	4.61E+00	4.15E-01	0.159	11.109	0
c3	2.10E-02	8.34E-04	0.688	25.133	0
c4	2.24E-03	2.56E-04	0.256	8.735	0
c5	-4.26E+05	7.66E+04	-0.056	-5.559	0

Table O.6: Cargo carrying capacity - coefficients for transversely framed container vessels. [Hekkenberg, 2013]

T	c1	c2	c3	R2
1.5	-3.50E-05	6.67E-01	-9.14E+01	0.995
2	-1.53E-05	7.10E-01	-8.61E+01	0.999
2.5	-1.02E-05	7.65E-01	-1.11E+02	1.000
3	-5.17E-06	7.86E-01	-1.23E+02	1.000
3.5	-2.27E-06	8.02E-01	-1.39E+02	1.000
4	-3.56E-06	8.23E-01	-1.71E+02	1.000
4.5	-3.75E-06	8.39E-01	-1.99E+02	1.000

Table O.7: Cargo carrying capacity - linear interpolated coefficients for transversely framed container vessels.

T	c1	c2	c3	R	
2	-1.53E-05	7.10E-01	-8.61E+01	0.999	Given
2.1	-1.43E-05	7.21E-01	-9.11E+01		
2.2	-1.33E-05	7.32E-01	-9.61E+01		Linearly Interpolated
2.3	-1.22E-05	7.43E-01	-1.01E+02		
2.4	-1.12E-05	7.54E-01	-1.06E+02		
2.5	-1.02E-05	7.65E-01	-1.11E+02	1	Given
2.6	-9.19E-06	7.69E-01	-1.13E+02		
2.7	-8.19E-06	7.73E-01	-1.16E+02		Linearly Interpolated
2.8	-7.18E-06	7.78E-01	-1.18E+02		
2.9	-6.18E-06	7.82E-01	-1.21E+02		
3	-5.17E-06	7.86E-01	-1.23E+02	1	Given

Table O.4: Yard cost - coefficients for transversely framed container vessels. [Hekkenberg, 2013]

	Unstandardized Coefficients		Standardized Coefficients		
	Value	Std. Error	Beta	t	Sig.
c1	6.88E+04	3.04E+04		2.261	0.024
c2	9.21E+02	3.13E+01	0.422	29.442	0
c3	-9.13E+01	5.46E+01	-0.041	-1.672	0.095
c4	5.02E+01	9.10E+00	0.08	5.521	0
c5	2.67E-03	5.49E-05	0.549	48.575	0
c6	2.65E+03	6.06E+02	0.059	4.377	0

Table O.5: Non-Yard cost - coefficients for dry bulk vessels. [Hekkenberg, 2013]

	Unstandardized Coefficients		Standardized Coefficients		
	Value	Std. Error	Beta	t	Sig.
c1	6.08E+05	2.23E+04		27.241	0
c2	4.01E+02	9.92E+01	0.034	4.039	0
c3	4.91E+01	3.26E+00	0.25	15.036	0
c4	4.74E+02	1.01E+01	0.696	46.757	0
c5	-2.08E+07	2.49E+06	-0.089	-8.364	0

Table O.8: My caption

SCCC	Weights (Lightweight) (t)					Cost Hull & Outfitting. (Excl. Handling eq.)			Cargo Capacity (Deadweight) (t)		Displacement	
Type	Steel	Other	Piping	M.E.O.	Total	Yard	Misc.	Total	Hekkenberg	Nabla-LW	cb	nabla
2208	190.66	43.25	2.13	52.77	289	€ 777,417.91	€ 810,154.18	€ 1,590,000.00	739	727	0.750	1016
2209	229.81	43.25	2.92	55.76	332	€ 947,663.60	€ 888,496.86	€ 1,840,000.00	896	926	0.782	1258
2210	264.83	46.87	3.58	58.01	374	€ 1,103,646.54	€ 950,812.65	€ 2,060,000.00	1026	1085	0.801	1459
2211	287.40	50.17	3.97	59.31	401	€ 1,204,931.32	€ 987,566.45	€ 2,200,000.00	1104	1180	0.811	1581
2212	311.27	53.47	4.37	60.58	430	€ 1,312,154.12	€ 1,023,837.42	€ 2,340,000.00	1182	1273	0.820	1703
2213	336.67	56.77	4.77	61.84	461	€ 1,425,837.74	€ 1,059,733.43	€ 2,490,000.00	1260	1363	0.827	1824
3208	213.09	50.91	2.31	56.88	324	€ 904,097.73	€ 894,996.21	€ 1,800,000.00	1013	1026	0.750	1350
3209	255.49	60.46	3.11	60.63	380	€ 1,103,681.77	€ 988,472.99	€ 2,100,000.00	1219	1291	0.782	1671
3210	293.64	68.43	3.77	63.53	430	€ 1,287,714.67	€ 1,063,284.55	€ 2,360,000.00	1390	1509	0.801	1939
3211	318.41	73.25	4.18	65.22	462	€ 1,407,860.90	€ 1,107,528.48	€ 2,520,000.00	1492	1638	0.811	2100
3212	344.82	78.06	4.58	66.88	495	€ 1,535,608.63	€ 1,151,248.54	€ 2,690,000.00	1594	1767	0.820	2262
3213	373.15	82.88	4.98	68.53	530	€ 1,671,665.02	€ 1,194,553.89	€ 2,870,000.00	1696	1894	0.827	2424
2308	206.04	43.25	2.21	55.39	307	€ 813,052.78	€ 839,109.61	€ 1,660,000.00	921	878	0.750	1185
2309	248.41	43.25	3.00	58.52	354	€ 991,430.79	€ 918,424.25	€ 1,910,000.00	1114	1112	0.782	1466
2310	286.21	48.75	3.67	60.89	400	€ 1,154,655.45	€ 981,963.14	€ 2,140,000.00	1274	1301	0.801	1701
2311	310.50	52.18	4.07	62.26	430	€ 1,260,539.32	€ 1,019,580.12	€ 2,290,000.00	1371	1413	0.811	1843
2312	336.15	55.61	4.47	63.61	460	€ 1,372,547.31	€ 1,056,785.98	€ 2,430,000.00	1468	1525	0.820	1985
2313	363.36	59.04	4.87	64.94	493	€ 1,491,216.45	€ 1,093,675.43	€ 2,590,000.00	1564	1634	0.827	2127
3308	220.73	50.91	2.34	58.07	333	€ 916,555.54	€ 907,602.32	€ 1,830,000.00	1115	1107	0.750	1440
3309	264.72	60.46	3.15	61.87	391	€ 1,118,881.76	€ 1,001,121.25	€ 2,130,000.00	1341	1391	0.782	1782
3310	304.21	68.43	3.82	64.81	442	€ 1,305,264.18	€ 1,076,194.93	€ 2,390,000.00	1529	1626	0.801	2068
3311	329.81	73.25	4.22	66.53	474	€ 1,426,853.99	€ 1,120,666.68	€ 2,550,000.00	1642	1766	0.811	2240
3312	357.05	78.06	4.62	68.22	508	€ 1,556,062.76	€ 1,164,655.12	€ 2,730,000.00	1754	1905	0.820	2413
3313	386.21	82.88	5.03	69.88	545	€ 1,693,596.86	€ 1,208,262.32	€ 2,910,000.00	1866	2040	0.827	2585
3408	234.77	52.31	2.41	60.22	350	€ 947,069.43	€ 932,932.93	€ 1,890,000.00	1304	1259	0.750	1609
3409	281.52	62.12	3.22	64.18	412	€ 1,156,242.95	€ 1,028,167.37	€ 2,190,000.00	1568	1579	0.782	1991
3410	323.38	70.31	3.90	67.23	465	€ 1,348,745.97	€ 1,104,955.99	€ 2,460,000.00	1788	1845	0.801	2310
3411	350.46	75.26	4.30	69.02	500	€ 1,474,238.09	€ 1,150,549.24	€ 2,630,000.00	1920	2003	0.811	2503
3412	379.21	80.20	4.71	70.79	535	€ 1,607,521.31	€ 1,195,708.68	€ 2,810,000.00	2051	2161	0.820	2696
3413	409.93	85.15	5.12	72.53	573	€ 1,749,316.85	€ 1,240,527.38	€ 2,990,000.00	2183	2315	0.827	2888

P

Detour Factor for Inland Waterway Transport

Thing that is interest for the intermodal cost build-up is the distances covered by the used modes. Since the road network is meshed much finer than that of rail and IWt, the route between origin and destination is the shortest. As a result, both rail and IWT have to cover additional distance, referred to as a detour. The detour factor for IWT depends often on the size of the waterway. The main roads tent to follow the main rivers as a result of historical preference. For smaller waterways, often perpendicular to some degree with respect to the main waterways, the detour factor becomes larger.

Table P.1 shows the following routes and their detour factors [Van Dorsser, 2015]. Looking at for instance route 3, where IWT and Road closely follow the same route, the detour factor is almost 1, meaning they are equally long. For route 4 there is however no direct waterway link, requiring a detour leading a detour factor of almost 1.3.

Since interest is put into smaller waterways, route 3 is not of interest. Applying the region of interest, route 5 is left out. Additional scoping regarding IWT within the Rhine delta, provides the information that the Rhine could be navigated with CEMT class Va vessels all the way up to Basel. This trip is also not of interest for the to be developed concept. This than brings the average detour factor up to 1.18. For reasons of convenience, the detour factor chosen for this research, focussing on small waterways, is chosen to be 1.2 on average.

Table P.1: Detour factors for a number of routes along waterways. (Modified version of [Van Dorsser, 2015])

	Route		Distance		Detour factor
	Origin	Destination	IWT	Road	
1	Kampen	Liège	311 km	275 km	1.13
2	Amsterdam	Willebroek	230 km	185 km	1.24
3	Amsterdam	Duisburg	222 km	217 km	1.02
4	Dortmund	Hanover	261 km	204 km	1.28
5	Hamburg	Dresden	571 km	500 km	1.14
6	Utrecht	Frankfurt	496 km	419 km	1.18
7	Nijmegen	Basel	721 km	631 km	1.14
8	Groningen	Ghent	393 km	361km	1.09
	Average				1.15
	Average excl 3, 5 & 7				1.18

Q
SCCC: Economies of Scale

This appendix contains additional data that forms the basis for the figures found in subsection 9.5.2.

Table Q.1: Expenses for four different SCCC at 480km sailing distance and 80% loading degree

(a) Annual operational expenses

Own SCCC Selection	3210	3211	3212	3213	Select from the drop-down menu				
Operating Scheme	B	B	B	B	default = A1				
Operating Scheme 2	S2	S2	S2	S2	default = S1				
Insurance	€ 56,043	€ 58,992	€ 62,091	€ 65,340	per annum (ship + HCGC)	100%	105%	111%	117%
R&M_Fixed	€ 46,059	€ 47,820	€ 49,587	€ 51,354	per annum	100%	104%	108%	111%
Overhead	€ 25,000	€ 25,000	€ 25,000	€ 25,000	per annum	100%	100%	100%	100%
Interest	€ 182,886	€ 193,584	€ 204,882	€ 216,780	per annum	100%	106%	112%	119%
Principle	€ 231,253	€ 244,780	€ 259,066	€ 274,111	per annum	100%	106%	112%	119%
Annual Fixed Cost	€ 541,241	€ 570,176	€ 600,626	€ 632,585	per annum	100%	105%	111%	117%
	€ 1,546	€ 1,629	€ 1,716	€ 1,807	per day	100%	105%	111%	117%
Fuel price	€ 650	€ 650	€ 650	€ 650	EUR/m3				
Fuel Cost	€ 253,682	€ 276,839	€ 285,435	€ 295,035	per annum	100%	109%	113%	116%
Labour cost	€ 382,120	€ 391,440	€ 391,440	€ 391,440	per annum	100%	102%	102%	102%
R&M_Variable	€ 37,759	€ 38,860	€ 39,963	€ 41,065	per annum	100%	103%	106%	109%
ARA-charge	€ 4,848	€ 5,333	€ 5,818	€ 6,302	per annum	100%	110%	120%	130%
Annual Variable Cost	€ 678,409	€ 712,472	€ 722,655	€ 733,842	per annum	100%	105%	107%	108%
	€ 1,938	€ 2,036	€ 2,065	€ 2,097	per day	100%	105%	107%	108%
Annual Cost	€ 1,219,651	€ 1,282,649	€ 1,323,281	€ 1,366,427	per annum	100%	105%	108%	112%

(b) Single trip o.o.p. sailing cost per TEU

Own SCCC Selection	3210	3211	3212	3213	Select from the drop-down menu				
Operating Scheme	B	B	B	B	default = A1				
Operating Scheme 2	S2	S2	S2	S2	default = S1				
Insurance	€ 11.68	€ 11.17	€ 10.78	€ 10.47	per single trip	100%	96%	92%	90%
R&M_Fixed	€ 9.60	€ 9.06	€ 8.61	€ 8.23	per single trip	100%	94%	90%	86%
Overhead	€ 5.21	€ 4.73	€ 4.34	€ 4.01	per single trip	100%	91%	83%	77%
Interest	€ 38.10	€ 36.66	€ 35.57	€ 34.74	per single trip	100%	96%	93%	91%
Principle	€ 48.18	€ 46.36	€ 44.98	€ 43.93	per single trip	100%	96%	93%	91%
Voyage Fixed Cost	€ 112.76	€ 107.99	€ 104.28	€ 101.38	per single trip	100%	96%	92%	90%
	€ 0.32	€ 0.31	€ 0.30	€ 0.29	per day per TEU	100%	96%	92%	90%
Fuel price	€ 650	€ 650	€ 650	€ 650	EUR/m3				
Fuel Cost	€ 52.85	€ 52.43	€ 49.55	€ 47.28	per single trip	100%	99%	94%	89%
Labour cost	€ 79.61	€ 74.14	€ 67.96	€ 62.73	per single trip	100%	93%	85%	79%
R&M_Variable	€ 7.87	€ 7.36	€ 6.94	€ 6.58	per single trip	100%	94%	88%	84%
ARA-charge	€ 1.01	€ 1.01	€ 1.01	€ 1.01	per single trip	100%	100%	100%	100%
Voyage Variable Cost	€ 141.34	€ 134.94	€ 125.46	€ 117.60	per single trip	100%	95%	89%	83%
	€ 0.40	€ 0.39	€ 0.36	€ 0.34	per day per TEU	100%	95%	89%	83%
Voyage Total Cost	€ 254.09	€ 242.93	€ 229.74	€ 218.98	per single trip	100%	96%	90%	86%

Table Q.2: Expenses for four different SCCC at 960km sailing distance and 80% loading degree

(a) Annual operational expenses

Own SCCC Selection	3210	3211	3212	3213	Select from the drop-down menu				
Operating Scheme	B	B	B	B	default = A1				
Operating Scheme 2	S2	S2	S2	S2	default = S1				
Insurance	€ 56,043	€ 58,992	€ 62,091	€ 65,340	per annum (ship + HCGC)	100%	105%	111%	117%
R&M_Fixed	€ 46,059	€ 47,820	€ 49,587	€ 51,354	per annum	100%	104%	108%	111%
Overhead	€ 25,000	€ 25,000	€ 25,000	€ 25,000	per annum	100%	100%	100%	100%
Interest	€ 182,886	€ 193,584	€ 204,882	€ 216,780	per annum	100%	106%	112%	119%
Principle	€ 231,253	€ 244,780	€ 259,066	€ 274,111	per annum	100%	106%	112%	119%
Annual Fixed Cost	€ 541,241	€ 570,176	€ 600,626	€ 632,585	per annum	100%	105%	111%	117%
	€ 1,546	€ 1,629	€ 1,716	€ 1,807	per day	100%	105%	111%	117%
Fuel price	€ 650	€ 650	€ 650	€ 650	EUR/m3				
Fuel Cost	€ 424,558	€ 460,516	€ 477,044	€ 495,511	per annum	100%	108%	112%	117%
Labour cost	€ 643,080	€ 652,400	€ 652,400	€ 652,400	per annum	100%	101%	101%	101%
R&M_Variable	€ 37,759	€ 38,860	€ 39,963	€ 41,065	per annum	100%	103%	106%	109%
ARA-charge	€ 4,848	€ 5,333	€ 5,818	€ 6,302	per annum	100%	110%	120%	130%
Annual Variable Cost	€ 1,110,245	€ 1,157,108	€ 1,175,224	€ 1,195,279	per annum	100%	104%	106%	108%
	€ 3,172	€ 3,306	€ 3,358	€ 3,415	per day	100%	104%	106%	108%
Annual Cost	€ 1,651,486	€ 1,727,285	€ 1,775,850	€ 1,827,863	per annum	100%	105%	108%	111%

(b) Single trip o.o.p. sailing cost per TEU

Own SCCC Selection	3210	3211	3212	3213	Select from the drop-down menu				
Operating Scheme	B	B	B	B	default = A1				
Operating Scheme 2	S2	S2	S2	S2	default = S1				
Insurance	€ 11.68	€ 11.17	€ 10.78	€ 10.47	per single trip	100%	96%	92%	90%
R&M_Fixed	€ 9.60	€ 9.06	€ 8.61	€ 8.23	per single trip	100%	94%	90%	86%
Overhead	€ 5.21	€ 4.73	€ 4.34	€ 4.01	per single trip	100%	91%	83%	77%
Interest	€ 38.10	€ 36.66	€ 35.57	€ 34.74	per single trip	100%	96%	93%	91%
Principle	€ 48.18	€ 46.36	€ 44.98	€ 43.93	per single trip	100%	96%	93%	91%
Voyage Fixed Cost	€ 112.76	€ 107.99	€ 104.28	€ 101.38	per single trip	100%	96%	92%	90%
	€ 0.32	€ 0.31	€ 0.30	€ 0.29	per day per TEU	100%	96%	92%	90%
Fuel price	€ 650	€ 650	€ 650	€ 650	EUR/m3				
Fuel Cost	€ 88.45	€ 87.22	€ 82.82	€ 79.41	per single trip	100%	99%	94%	90%
Labour cost	€ 133.98	€ 123.56	€ 113.26	€ 104.55	per single trip	100%	92%	85%	78%
R&M_Variable	€ 7.87	€ 7.36	€ 6.94	€ 6.58	per single trip	100%	94%	88%	84%
ARA-charge	€ 1.01	€ 1.01	€ 1.01	€ 1.01	per single trip	100%	100%	100%	100%
Voyage Variable Cost	€ 231.30	€ 219.15	€ 204.03	€ 191.55	per single trip	100%	95%	88%	83%
	€ 0.66	€ 0.63	€ 0.58	€ 0.55	per day per TEU	100%	95%	88%	83%
Voyage Total Cost	€ 344.06	€ 327.14	€ 308.31	€ 292.93	per single trip	100%	95%	90%	85%

R

SCCC: Loading degree

This appendix contains additional data that forms the basis for the figures found in subsection 9.5.3.

Table R.1: Expenses for three different SCCC at 300km sailing distance and variable loading degree.

(a) Annual operational expenses

Own SCCC Selection	3409	3409	3309	3409	3209	Select from the drop-down menu	3409	3409	3309	3409	3209
Operating Scheme	A2	A2	A2	A2	A2	default = A1	100%	75%	100%	50%	100%
Operating Scheme 2	S1	S1	S1	S1	S1	default = S1	10800	8100	8100	5400	5400
Insurance	€ 52,944	€ 52,944	€ 52,044	€ 52,944	€ 51,594	per annum (ship + HCGC)	100%	100%	98%	100%	97%
R&M_Fixed	€ 45,619	€ 45,619	€ 44,323	€ 45,619	€ 43,635	per annum	100%	100%	97%	100%	96%
Overhead	€ 27,000	€ 25,000	€ 25,000	€ 25,000	€ 25,000	per annum	100%	93%	93%	93%	93%
Interest	€ 171,588	€ 171,588	€ 167,988	€ 171,588	€ 166,188	per annum	100%	100%	98%	100%	97%
Principle	€ 216,967	€ 216,967	€ 212,415	€ 216,967	€ 210,139	per annum	100%	100%	98%	100%	97%
Annual Fixed Cost	€ 514,118	€ 512,118	€ 501,771	€ 512,118	€ 496,556	per annum	100%	100%	98%	100%	97%
	€ 2,056	€ 2,048	€ 2,007	€ 2,048	€ 1,986	per day	100%	100%	98%	100%	97%
Fuel price	€ 650	€ 650	€ 650	€ 650	€ 650	EUR/m3					
Fuel Cost	€ 313,810	€ 275,039	€ 253,291	€ 243,467	€ 201,387	per annum	100%	88%	81%	78%	64%
Labour cost	€ 157,250	€ 157,250	€ 157,250	€ 157,250	€ 157,250	per annum	100%	100%	100%	100%	100%
R&M_Variable	€ 37,106	€ 37,106	€ 36,667	€ 37,106	€ 36,434	per annum	100%	100%	99%	100%	98%
ARA-charge	€ 10,908	€ 8,181	€ 8,181	€ 5,454	€ 5,454	per annum	100%	75%	75%	50%	50%
Annual Variable Cost	€ 519,074	€ 477,576	€ 455,390	€ 443,277	€ 400,525	per annum	100%	92%	88%	85%	77%
	€ 2,076	€ 1,910	€ 1,822	€ 1,773	€ 1,602	per day	100%	92%	88%	85%	77%
Annual Cost	€ 1,033,192	€ 989,694	€ 957,160	€ 955,396	€ 897,081	per annum	100%	96%	93%	92%	87%

(b) Single trip o.o.p. sailing cost per TEU

Own SCCC Selection	3409	3409	3309	3409	3209	Select from the drop-down menu	3409	3409	3309	3409	3209
Operating Scheme	A2	A2	A2	A2	A2	default = A1	100%	75%	100%	50%	100%
Operating Scheme 2	S1	S1	S1	S1	S1	default = S1	10800	8100	8100	5400	5400
Insurance	€ 4.90	€ 6.54	€ 6.43	€ 9.80	€ 9.55	per single trip	100%	133%	131%	200%	195%
R&M_Fixed	€ 4.22	€ 5.63	€ 5.47	€ 8.45	€ 8.08	per single trip	100%	133%	130%	200%	191%
Overhead	€ 2.50	€ 3.09	€ 3.09	€ 4.63	€ 4.63	per single trip	100%	123%	123%	185%	185%
Interest	€ 15.89	€ 21.18	€ 20.74	€ 31.78	€ 30.78	per single trip	100%	133%	131%	200%	194%
Principle	€ 20.09	€ 26.79	€ 26.22	€ 40.18	€ 38.91	per single trip	100%	133%	131%	200%	194%
Voyage Fixed Cost	€ 47.60	€ 63.22	€ 61.95	€ 94.84	€ 91.95	per single trip	100%	133%	130%	199%	193%
	€ 0.19	€ 0.25	€ 0.25	€ 0.38	€ 0.37	per day per TEU	100%	133%	130%	199%	193%
Fuel price	€ 650	€ 650	€ 650	€ 650	€ 650	EUR/m3					
Fuel Cost	€ 29.06	€ 33.96	€ 31.27	€ 45.09	€ 37.29	per single trip	100%	117%	108%	155%	128%
Labour cost	€ 14.56	€ 19.41	€ 19.41	€ 29.12	€ 29.12	per single trip	100%	133%	133%	200%	200%
R&M_Variable	€ 3.44	€ 4.58	€ 4.53	€ 6.87	€ 6.75	per single trip	100%	133%	132%	200%	196%
ARA-charge	€ 1.01	€ 1.01	€ 1.01	€ 1.01	€ 1.01	per single trip	100%	100%	100%	100%	100%
Voyage Variable Cost	€ 48.06	€ 58.96	€ 56.22	€ 82.09	€ 74.17	per single trip	100%	123%	117%	171%	154%
	€ 0.19	€ 0.24	€ 0.22	€ 0.33	€ 0.30	per day per TEU	100%	123%	117%	171%	154%
Voyage Total Cost	€ 95.67	€ 122.18	€ 118.17	€ 176.93	€ 166.13	per single trip	100%	128%	124%	185%	174%

S

SCCC: Sailing Speed

This appendix contains additional data that forms the basis for the figures found in subsection 9.5.4.

Table S.1: Expenses for six different sailing speeds at 360km sailing distance for an 80% loaded *'2210'* SCCC.

(a) Annual operational expenses

Own SCCC Selection	2210	2210	2210	2210	2210	2210	Select from the drop-down menu	13	14	15	16	17	18
Operating Scheme	A2	A2	A2	A2	A2	A2	default = A1						
Operating Scheme 2	S2	S2	S2	S2	S2	S2	default = S1						
Insurance	€ 47,414	€ 47,414	€ 47,414	€ 47,414	€ 47,414	€ 47,414	per annum (ship + HCGC)	100%	100%	100%	100%	100%	100%
R&M_Fixed	€ 36,516	€ 36,516	€ 36,516	€ 36,516	€ 36,516	€ 36,516	per annum	100%	100%	100%	100%	100%	100%
Overhead	€ 25,000	€ 25,000	€ 25,000	€ 25,000	€ 25,000	€ 25,000	per annum	100%	100%	100%	100%	100%	100%
Interest	€ 156,629	€ 156,629	€ 156,629	€ 156,629	€ 156,629	€ 156,629	per annum	100%	100%	100%	100%	100%	100%
Principle	€ 198,052	€ 198,052	€ 198,052	€ 198,052	€ 198,052	€ 198,052	per annum	100%	100%	100%	100%	100%	100%
Annual Fixed Cost	€ 463,611	€ 463,611	€ 463,611	€ 463,611	€ 463,611	€ 463,611	per annum	100%	100%	100%	100%	100%	100%
	€ 1,854	€ 1,854	€ 1,854	€ 1,854	€ 1,854	€ 1,854	per day	100%	100%	100%	100%	100%	100%
Fuel price	€ 650	€ 650	€ 650	€ 650	€ 650	€ 650	EUR/m3						
Fuel Cost	€ 172,073	€ 182,319	€ 198,517	€ 216,458	€ 234,245	€ 254,319	per annum	100%	106%	115%	126%	136%	148%
Labour cost	€ 157,250	€ 157,250	€ 157,250	€ 157,250	€ 125,800	€ 125,800	per annum	100%	100%	100%	100%	80%	80%
R&M_Variable	€ 30,184	€ 30,184	€ 30,184	€ 30,184	€ 30,184	€ 30,184	per annum	100%	100%	100%	100%	100%	100%
ARA-charge	€ 3,232	€ 3,232	€ 3,232	€ 3,232	€ 3,232	€ 3,232	per annum	100%	100%	100%	100%	100%	100%
Annual Variable Cost	€ 362,739	€ 372,985	€ 389,182	€ 407,124	€ 393,461	€ 413,535	per annum	100%	103%	107%	112%	108%	114%
	€ 1,451	€ 1,492	€ 1,557	€ 1,629	€ 1,574	€ 1,654	per day	100%	103%	107%	112%	108%	114%
Annual Cost	€ 826,350	€ 836,595	€ 852,793	€ 870,735	€ 857,072	€ 877,146	per annum	100%	101%	103%	105%	104%	106%

(b) Single trip o.o.p. sailing cost per TEU

Own SCCC Selection	2210	2210	2210	2210	2210	2210	Select from the drop-down menu	13	14	15	16	17	18
Operating Scheme	A2	A2	A2	A2	A2	A2	default = A1						
Operating Scheme 2	S2	S2	S2	S2	S2	S2	default = S1						
Insurance	€ 14.82	€ 14.82	€ 14.82	€ 14.82	€ 14.82	€ 14.82	per single trip	100%	100%	100%	100%	100%	100%
R&M_Fixed	€ 11.41	€ 11.41	€ 11.41	€ 11.41	€ 11.41	€ 11.41	per single trip	100%	100%	100%	100%	100%	100%
Overhead	€ 7.81	€ 7.81	€ 7.81	€ 7.81	€ 7.81	€ 7.81	per single trip	100%	100%	100%	100%	100%	100%
Interest	€ 48.95	€ 48.95	€ 48.95	€ 48.95	€ 48.95	€ 48.95	per single trip	100%	100%	100%	100%	100%	100%
Principle	€ 61.89	€ 61.89	€ 61.89	€ 61.89	€ 61.89	€ 61.89	per single trip	100%	100%	100%	100%	100%	100%
Voryage Fixed Cost	€ 144.88	€ 144.88	€ 144.88	€ 144.88	€ 144.88	€ 144.88	per single trip	100%	100%	100%	100%	100%	100%
	€ 0.58	€ 0.58	€ 0.58	€ 0.58	€ 0.58	€ 0.58	per day per TEU	100%	100%	100%	100%	100%	100%
Fuel price	€ 650	€ 650	€ 650	€ 650	€ 650	€ 650	EUR/m3						
Fuel Cost	€ 53.77	€ 56.97	€ 62.04	€ 67.64	€ 73.20	€ 79.47	per single trip	100%	106%	115%	126%	136%	148%
Labour cost	€ 49.14	€ 49.14	€ 49.14	€ 49.14	€ 39.31	€ 39.31	per single trip	100%	100%	100%	100%	80%	80%
R&M_Variable	€ 9.43	€ 9.43	€ 9.43	€ 9.43	€ 9.43	€ 9.43	per single trip	100%	100%	100%	100%	100%	100%
ARA-charge	€ 1.01	€ 1.01	€ 1.01	€ 1.01	€ 1.01	€ 1.01	per single trip	100%	100%	100%	100%	100%	100%
Voyage Variable Cost	€ 113.36	€ 116.56	€ 121.62	€ 127.23	€ 122.96	€ 129.23	per single trip	100%	103%	107%	112%	108%	114%
	€ 0.45	€ 0.47	€ 0.49	€ 0.51	€ 0.49	€ 0.52	per day per TEU	100%	103%	107%	112%	108%	114%
Voyage Total Cost	€ 258.23	€ 261.44	€ 266.50	€ 272.10	€ 267.83	€ 274.11	per single trip	100%	101%	103%	105%	104%	106%

Table S.2: Expenses for six different sailing speeds at 480km sailing distance for an 80% loaded *'2210'* SCCC.

(a) Annual operational expenses

Own SCCC Selection	2210	2210	2210	2210	2210	2210	Select from the drop-down menu	13	14	15	16	17	18
Operating Scheme	A2	A2	A2	A2	A2	A2	default = A1						
Operating Scheme 2	S2	S2	S2	S2	S2	S2	default = S1						
Insurance	€ 47,414	€ 47,414	€ 47,414	€ 47,414	€ 47,414	€ 47,414	per annum (ship + HCGC)	100%	100%	100%	100%	100%	100%
R&M_Fixed	€ 36,516	€ 36,516	€ 36,516	€ 36,516	€ 36,516	€ 36,516	per annum	100%	100%	100%	100%	100%	100%
Overhead	€ 25,000	€ 25,000	€ 25,000	€ 25,000	€ 25,000	€ 25,000	per annum	100%	100%	100%	100%	100%	100%
Interest	€ 156,629	€ 156,629	€ 156,629	€ 156,629	€ 156,629	€ 156,629	per annum	100%	100%	100%	100%	100%	100%
Principle	€ 198,052	€ 198,052	€ 198,052	€ 198,052	€ 198,052	€ 198,052	per annum	100%	100%	100%	100%	100%	100%
Annual Fixed Cost	€ 463,611	€ 463,611	€ 463,611	€ 463,611	€ 463,611	€ 463,611	per annum	100%	100%	100%	100%	100%	100%
	€ 2,318	€ 2,318	€ 2,318	€ 1,854	€ 1,854	€ 1,854	per day	100%	100%	100%	80%	80%	80%
Fuel price	€ 650	€ 650	€ 650	€ 650	€ 650	€ 650	EUR/m3						
Fuel Cost	€ 102,982	€ 109,741	€ 120,176	€ 263,636	€ 286,976	€ 311,954	per annum	100%	107%	117%	256%	279%	303%
Labour cost	€ 125,800	€ 125,800	€ 125,800	€ 157,250	€ 157,250	€ 157,250	per annum	100%	100%	100%	125%	125%	125%
R&M_Variable	€ 30,184	€ 30,184	€ 30,184	€ 30,184	€ 30,184	€ 30,184	per annum	100%	100%	100%	100%	100%	100%
ARA-charge	€ 3,232	€ 3,232	€ 3,232	€ 3,232	€ 3,232	€ 3,232	per annum	100%	100%	100%	100%	100%	100%
Annual Variable Cost	€ 262,198	€ 268,957	€ 279,392	€ 454,302	€ 477,642	€ 502,620	per annum	100%	103%	107%	173%	182%	192%
	€ 1,311	€ 1,345	€ 1,397	€ 1,817	€ 1,911	€ 2,010	per day	100%	103%	107%	139%	146%	153%
Annual Cost	€ 725,809	€ 732,568	€ 743,003	€ 917,913	€ 941,253	€ 966,231	per annum	100%	101%	102%	126%	130%	133%

(b) Single trip o.o.p. sailing cost per TEU

Own SCCC Selection	2210	2210	2210	2210	2210	2210	Select from the drop-down menu	13	14	15	16	17	18
Operating Scheme	A2	A2	A2	A2	A2	A2	default = A1						
Operating Scheme 2	S2	S2	S2	S2	S2	S2	default = S1						
Insurance	€ 29.63	€ 29.63	€ 29.63	€ 14.82	€ 14.82	€ 14.82	per single trip	100%	100%	100%	50%	50%	50%
R&M_Fixed	€ 22.82	€ 22.82	€ 22.82	€ 11.41	€ 11.41	€ 11.41	per single trip	100%	100%	100%	50%	50%	50%
Overhead	€ 15.63	€ 15.63	€ 15.63	€ 7.81	€ 7.81	€ 7.81	per single trip	100%	100%	100%	50%	50%	50%
Interest	€ 97.89	€ 97.89	€ 97.89	€ 48.95	€ 48.95	€ 48.95	per single trip	100%	100%	100%	50%	50%	50%
Principle	€ 123.78	€ 123.78	€ 123.78	€ 61.89	€ 61.89	€ 61.89	per single trip	100%	100%	100%	50%	50%	50%
Voryage Fixed Cost	€ 289.76	€ 289.76	€ 289.76	€ 144.88	€ 144.88	€ 144.88	per single trip	100%	100%	100%	50%	50%	50%
	€ 1.45	€ 1.45	€ 1.45	€ 0.58	€ 0.58	€ 0.58	per day per TEU	100%	100%	100%	40%	40%	40%
Fuel price	€ 650	€ 650	€ 650	€ 650	€ 650	€ 650	EUR/m3						
Fuel Cost	€ 64.36	€ 68.59	€ 75.11	€ 82.39	€ 89.68	€ 97.49	per single trip	100%	107%	117%	128%	139%	151%
Labour cost	€ 78.63	€ 78.63	€ 78.63	€ 49.14	€ 49.14	€ 49.14	per single trip	100%	100%	100%	63%	63%	63%
R&M_Variable	€ 18.86	€ 18.86	€ 18.86	€ 9.43	€ 9.43	€ 9.43	per single trip	100%	100%	100%	50%	50%	50%
ARA-charge	€ 2.02	€ 2.02	€ 2.02	€ 1.01	€ 1.01	€ 1.01	per single trip	100%	100%	100%	50%	50%	50%
Voyage Variable Cost	€ 163.87	€ 168.10	€ 174.62	€ 141.97	€ 149.26	€ 157.07	per single trip	100%	103%	107%	87%	91%	96%
	€ 0.82	€ 0.84	€ 0.87	€ 0.57	€ 0.60	€ 0.63	per day per TEU	100%	103%	107%	69%	73%	77%
Voyage Total Cost	€ 453.63	€ 457.85	€ 464.38	€ 286.85	€ 294.14	€ 301.95	per single trip	100%	101%	102%	63%	65%	67%

Table S.3: Expenses for six different sailing speeds at 480km sailing distance for an 80% loaded *'2210'* SCCC with every available day used for navigation.

(a) Annual operational expenses

Own SCCC Selection	2210	2210	2210	2210	2210	2210	Select from the drop-down menu	13	14	15	16	17	18
Operating Scheme	A2	A2	A2	A2	A2	A2	default = A1						
Operating Scheme 2	S2	S2	S2	S2	S2	S2	default = S1						
Insurance	€ 47,414	€ 47,414	€ 47,414	€ 47,414	€ 47,414	€ 47,414	per annum (ship + HCGC)	100%	100%	100%	100%	100%	100%
R&M_Fixed	€ 36,516	€ 36,516	€ 36,516	€ 36,516	€ 36,516	€ 36,516	per annum	100%	100%	100%	100%	100%	100%
Overhead	€ 25,000	€ 25,000	€ 25,000	€ 25,000	€ 25,000	€ 25,000	per annum	100%	100%	100%	100%	100%	100%
Interest	€ 156,629	€ 156,629	€ 156,629	€ 156,629	€ 156,629	€ 156,629	per annum	100%	100%	100%	100%	100%	100%
Principle	€ 198,052	€ 198,052	€ 198,052	€ 198,052	€ 198,052	€ 198,052	per annum	100%	100%	100%	100%	100%	100%
Annual Fixed Cost	€ 463,611	€ 463,611	€ 463,611	€ 463,611	€ 463,611	€ 463,611	per annum	100%	100%	100%	100%	100%	100%
	€ 2,119	€ 2,119	€ 2,119	€ 1,854	€ 1,854	€ 1,854	per day	100%	100%	100%	87%	87%	87%
Fuel price	€ 650	€ 650	€ 650	€ 650	€ 650	€ 650	EUR/m3						
Fuel Cost	€ 180,218	€ 192,047	€ 210,309	€ 263,636	€ 286,976	€ 311,954	per annum	100%	107%	117%	146%	159%	173%
Labour cost	€ 220,150	€ 220,150	€ 220,150	€ 157,250	€ 157,250	€ 157,250	per annum	100%	100%	100%	71%	71%	71%
R&M_Variable	€ 30,184	€ 30,184	€ 30,184	€ 30,184	€ 30,184	€ 30,184	per annum	100%	100%	100%	100%	100%	100%
ARA-charge	€ 2,828	€ 2,828	€ 2,828	€ 3,232	€ 3,232	€ 3,232	per annum	100%	100%	100%	114%	114%	114%
Annual Variable Cost	€ 433,380	€ 445,209	€ 463,471	€ 454,302	€ 477,642	€ 502,620	per annum	100%	103%	107%	105%	110%	116%
	€ 1,981	€ 2,035	€ 2,119	€ 1,817	€ 1,911	€ 2,010	per day	100%	103%	107%	92%	96%	101%
Annual Cost	€ 896,991	€ 908,820	€ 927,082	€ 917,913	€ 941,253	€ 966,231	per annum	100%	101%	103%	102%	105%	108%

(b) Single trip o.o.p. sailing cost per TEU

Own SCCC Selection	2210	2210	2210	2210	2210	2210	Select from the drop-down menu	13	14	15	16	17	18
Operating Scheme	A2	A2	A2	A2	A2	A2	default = A1						
Operating Scheme 2	S2	S2	S2	S2	S2	S2	default = S1						
Insurance	€ 16.93	€ 16.93	€ 16.93	€ 14.82	€ 14.82	€ 14.82	per single trip	100%	100%	100%	88%	88%	88%
R&M_Fixed	€ 13.04	€ 13.04	€ 13.04	€ 11.41	€ 11.41	€ 11.41	per single trip	100%	100%	100%	88%	88%	88%
Overhead	€ 8.93	€ 8.93	€ 8.93	€ 7.81	€ 7.81	€ 7.81	per single trip	100%	100%	100%	88%	88%	88%
Interest	€ 55.94	€ 55.94	€ 55.94	€ 48.95	€ 48.95	€ 48.95	per single trip	100%	100%	100%	88%	88%	88%
Principle	€ 70.73	€ 70.73	€ 70.73	€ 61.89	€ 61.89	€ 61.89	per single trip	100%	100%	100%	88%	88%	88%
Voryage Fixed Cost	€ 165.58	€ 165.58	€ 165.58	€ 144.88	€ 144.88	€ 144.88	per single trip	100%	100%	100%	88%	88%	88%
	€ 0.76	€ 0.76	€ 0.76	€ 0.58	€ 0.58	€ 0.58	per day per TEU	100%	100%	100%	77%	77%	77%
Fuel price	€ 650	€ 650	€ 650	€ 650	€ 650	€ 650	EUR/m3						
Fuel Cost	€ 64.36	€ 68.59	€ 75.11	€ 82.39	€ 89.68	€ 97.49	per single trip	100%	107%	117%	128%	139%	151%
Labour cost	€ 78.63	€ 78.63	€ 78.63	€ 49.14	€ 49.14	€ 49.14	per single trip	100%	100%	100%	63%	63%	63%
R&M_Variable	€ 10.78	€ 10.78	€ 10.78	€ 9.43	€ 9.43	€ 9.43	per single trip	100%	100%	100%	88%	88%	88%
ARA-charge	€ 1.01	€ 1.01	€ 1.01	€ 1.01	€ 1.01	€ 1.01	per single trip	100%	100%	100%	100%	100%	100%
Voyage Variable Cost	€ 154.78	€ 159.00	€ 165.53	€ 141.97	€ 149.26	€ 157.07	per single trip	100%	103%	107%	92%	96%	101%
	€ 0.71	€ 0.73	€ 0.76	€ 0.57	€ 0.60	€ 0.63	per day per TEU	100%	103%	107%	80%	84%	89%
Voyage Total Cost	€ 320.35	€ 324.58	€ 331.10	€ 286.85	€ 294.14	€ 301.95	per single trip	100%	101%	103%	90%	92%	94%

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SCCC: Sailing Regimen

This appendix contains additional data that forms the basis for the figures found in subsection 9.5.5.

Table T.1: Expenses for 2 different sailing regimens (A2 & B) at three different sailing distances for an 80% loaded *'2312'* SCCC with every available day used for navigation.

(a) Annual operational expenses

Own SCCC Selection	2312	2312	2312	2312	2312	2312	Select from the drop-down menu	2312	2312	2312	2312	2312	2312
Operating Scheme	A2	B	A2	B	A2	B	default = A1	300	300	600	600	900	900
Operating Scheme 2	S2	S2	S2	S2	S2	S2	default = S1						
Insurance	€ 53,843	€ 53,843	€ 53,843	€ 53,843	€ 53,843	€ 53,843	per annum (ship + HCGC)	100%	100%	100%	100%	100%	100%
R&M_Fixed	€ 40,997	€ 40,997	€ 40,997	€ 40,997	€ 40,997	€ 40,997	per annum	100%	100%	100%	100%	100%	100%
Overhead	€ 25,000	€ 25,000	€ 25,000	€ 25,000	€ 25,000	€ 25,000	per annum	100%	100%	100%	100%	100%	100%
Interest	€ 180,586	€ 180,586	€ 180,586	€ 180,586	€ 180,586	€ 180,586	per annum	100%	100%	100%	100%	100%	100%
Principle	€ 228,344	€ 228,344	€ 228,344	€ 228,344	€ 228,344	€ 228,344	per annum	100%	100%	100%	100%	100%	100%
Annual Fixed Cost	€ 528,770	€ 528,770	€ 528,770	€ 528,770	€ 528,770	€ 528,770	per annum	100%	100%	100%	100%	100%	100%
	€ 2,115	€ 1,511	€ 1,511	€ 1,511	€ 1,511	€ 1,511	per day	100%	71%	71%	71%	71%	71%
Fuel price	€ 650	€ 650	€ 650	€ 650	€ 650	€ 650	EUR/m3						
Fuel Cost	€ 301,322	€ 620,188	€ 390,994	€ 663,728	€ 410,720	€ 674,915	per annum	100%	206%	130%	220%	136%	224%
Labour cost	€ 201,500	€ 652,400	€ 282,100	€ 652,400	€ 282,100	€ 652,400	per annum	100%	324%	140%	324%	140%	324%
R&M_Variable	€ 32,509	€ 32,509	€ 32,509	€ 32,509	€ 32,509	€ 32,509	per annum	100%	100%	100%	100%	100%	100%
ARA-charge	€ 5,818	€ 5,818	€ 5,818	€ 5,818	€ 5,818	€ 5,818	per annum	100%	100%	100%	100%	100%	100%
Annual Variable Cost	€ 541,148	€ 1,310,915	€ 711,420	€ 1,354,454	€ 731,147	€ 1,365,641	per annum	100%	242%	131%	250%	135%	252%
	€ 2,165	€ 3,745	€ 2,033	€ 3,870	€ 2,089	€ 3,902	per day	100%	173%	94%	179%	97%	180%
Annual Cost	€ 1,069,917	€ 1,839,684	€ 1,240,190	€ 1,883,224	€ 1,259,916	€ 1,894,411	per annum	100%	172%	116%	176%	118%	177%

(b) Single trip o.o.p. sailing cost per TEU

Own SCCC Selection	2312	2312	2312	2312	2312	2312	Select from the drop-down menu	2312	2312	2312	2312	2312	2312
Operating Scheme	A2	B	A2	B	A2	B	default = A1	300	300	400	400	600	600
Operating Scheme 2	S2	S2	S2	S2	S2	S2	default = S1						
Insurance	€ 9.35	€ 4.54	€ 12.02	€ 7.08	€ 16.02	€ 9.75	per single trip	100%	49%	129%	76%	171%	104%
R&M_Fixed	€ 7.12	€ 3.46	€ 9.15	€ 5.39	€ 12.20	€ 7.42	per single trip	100%	49%	129%	76%	171%	104%
Overhead	€ 4.34	€ 2.11	€ 5.58	€ 3.29	€ 7.44	€ 4.53	per single trip	100%	49%	129%	76%	171%	104%
Interest	€ 31.35	€ 15.23	€ 40.31	€ 23.74	€ 53.75	€ 32.70	per single trip	100%	49%	129%	76%	171%	104%
Principle	€ 39.64	€ 19.26	€ 50.97	€ 30.02	€ 67.96	€ 41.34	per single trip	100%	49%	129%	76%	171%	104%
Voryage Fixed Cost	€ 91.80	€ 44.59	€ 118.03	€ 69.51	€ 157.37	€ 95.73	per single trip	100%	49%	129%	76%	171%	104%
	€ 0.37	€ 0.13	€ 0.34	€ 0.20	€ 0.45	€ 0.27	per day per TEU	100%	35%	92%	54%	122%	74%
Fuel price	€ 650	€ 650	€ 650	€ 650	€ 650	€ 650	EUR/m3						
Fuel Cost	€ 52.31	€ 52.30	€ 87.28	€ 87.25	€ 122.24	€ 122.19	per single trip	100%	100%	167%	167%	234%	234%
Labour cost	€ 34.98	€ 55.01	€ 62.97	€ 85.76	€ 83.96	€ 118.12	per single trip	100%	157%	180%	245%	240%	338%
R&M_Variable	€ 5.64	€ 2.74	€ 7.26	€ 4.27	€ 9.68	€ 5.89	per single trip	100%	49%	129%	76%	171%	104%
ARA-charge	€ 1.01	€ 0.49	€ 1.30	€ 0.76	€ 1.73	€ 1.05	per single trip	100%	49%	129%	76%	171%	104%
Voyage Variable Cost	€ 93.95	€ 110.54	€ 158.80	€ 178.04	€ 217.60	€ 247.25	per single trip	100%	118%	169%	190%	232%	263%
	€ 0.38	€ 0.32	€ 0.45	€ 0.51	€ 0.62	€ 0.71	per day per TEU	100%	84%	121%	135%	165%	188%
Voyage Total Cost	€ 185.75	€ 155.13	€ 276.83	€ 247.55	€ 374.98	€ 342.99	per single trip	100%	84%	149%	133%	202%	185%

Table T.2: Expenses for 2 different sailing regimens (A2 & B) at three different sailing distances for an 80% loaded *'2312'* SCCC with regular navigation only. Regular is a multiple of half a week.

(a) Annual operational expenses

Own SCCC Selection	2312	2312	2312	2312	2312	2312	Select from the drop-down menu	2312	2312	2312	2312	2312	2312
Operating Scheme	A2	B	A2	B	A2	B	default = A1	300	300	600	600	900	900
Operating Scheme 2	S2	S2	S2	S2	S2	S2	default = S1						
Insurance	€ 53,843	€ 53,843	€ 53,843	€ 53,843	€ 53,843	€ 53,843	per annum (ship + HCGC)	100%	100%	100%	100%	100%	100%
R&M_Fixed	€ 40,997	€ 40,997	€ 40,997	€ 40,997	€ 40,997	€ 40,997	per annum	100%	100%	100%	100%	100%	100%
Overhead	€ 25,000	€ 25,000	€ 25,000	€ 25,000	€ 25,000	€ 25,000	per annum	100%	100%	100%	100%	100%	100%
Interest	€ 180,586	€ 180,586	€ 180,586	€ 180,586	€ 180,586	€ 180,586	per annum	100%	100%	100%	100%	100%	100%
Principle	€ 228,344	€ 228,344	€ 228,344	€ 228,344	€ 228,344	€ 228,344	per annum	100%	100%	100%	100%	100%	100%
Annual Fixed Cost	€ 528,770	€ 528,770	€ 528,770	€ 528,770	€ 528,770	€ 528,770	per annum	100%	100%	100%	100%	100%	100%
	€ 2,115	€ 1,555	€ 2,350	€ 1,995	€ 2,203	€ 2,173	per day	100%	74%	111%	94%	104%	103%
Fuel price	€ 650	€ 650	€ 650	€ 650	€ 650	€ 650	EUR/m3						
Fuel Cost	€ 301,322	€ 602,469	€ 251,353	€ 502,537	€ 281,637	€ 469,227	per annum	100%	200%	83%	167%	93%	156%
Labour cost	€ 201,500	€ 633,760	€ 181,350	€ 493,960	€ 193,440	€ 453,573	per annum	100%	315%	90%	245%	96%	225%
R&M_Variable	€ 32,509	€ 32,509	€ 32,509	€ 32,509	€ 32,509	€ 32,509	per annum	100%	100%	100%	100%	100%	100%
ARA-charge	€ 5,818	€ 5,818	€ 5,818	€ 5,818	€ 5,818	€ 5,818	per annum	100%	100%	100%	100%	100%	100%
Annual Variable Cost	€ 541,148	€ 1,274,555	€ 471,030	€ 1,034,823	€ 513,403	€ 961,126	per annum	100%	236%	87%	191%	95%	178%
	€ 2,165	€ 3,749	€ 2,093	€ 3,905	€ 2,139	€ 3,950	per day	100%	173%	97%	180%	99%	182%
Annual Cost	€ 1,069,917	€ 1,803,325	€ 999,799	€ 1,563,593	€ 1,042,173	€ 1,489,896	per annum	100%	169%	93%	146%	97%	139%

(b) Single trip o.o.p. sailing cost per TEU

Own SCCC Selection	2312	2312	2312	2312	2312	2312	Select from the drop-down menu	2312	2312	2312	2312	2312	2312
Operating Scheme	A2	B	A2	B	A2	B	default = A1	300	300	400	400	600	600
Operating Scheme 2	S2	S2	S2	S2	S2	S2	default = S1						
Insurance	€ 9.35	€ 4.67	€ 18.70	€ 9.35	€ 23.37	€ 14.02	per single trip	100%	50%	200%	100%	250%	150%
R&M_Fixed	€ 7.12	€ 3.56	€ 14.24	€ 7.12	€ 17.79	€ 10.68	per single trip	100%	50%	200%	100%	250%	150%
Overhead	€ 4.34	€ 2.17	€ 8.68	€ 4.34	€ 10.85	€ 6.51	per single trip	100%	50%	200%	100%	250%	150%
Interest	€ 31.35	€ 15.68	€ 62.70	€ 31.35	€ 78.38	€ 47.03	per single trip	100%	50%	200%	100%	250%	150%
Principle	€ 39.64	€ 19.82	€ 79.29	€ 39.64	€ 99.11	€ 59.46	per single trip	100%	50%	200%	100%	250%	150%
Voyage Fixed Cost	€ 91.80	€ 45.90	€ 183.60	€ 91.80	€ 229.50	€ 137.70	per single trip	100%	50%	200%	100%	250%	150%
	€ 0.37	€ 0.14	€ 0.82	€ 0.35	€ 0.96	€ 0.57	per day per TEU	100%	37%	222%	94%	260%	154%
Fuel price	€ 650	€ 650	€ 650	€ 650	€ 650	€ 650	EUR/m3						
Fuel Cost	€ 52.31	€ 52.30	€ 87.28	€ 87.25	€ 122.24	€ 122.19	per single trip	100%	100%	167%	167%	234%	234%
Labour cost	€ 34.98	€ 55.01	€ 62.97	€ 85.76	€ 83.96	€ 118.12	per single trip	100%	157%	180%	245%	240%	338%
R&M_Variable	€ 5.64	€ 2.82	€ 11.29	€ 5.64	€ 14.11	€ 8.47	per single trip	100%	50%	200%	100%	250%	150%
ARA-charge	€ 1.01	€ 0.51	€ 2.02	€ 1.01	€ 2.53	€ 1.52	per single trip	100%	50%	200%	100%	250%	150%
Voyage Variable Cost	€ 93.95	€ 110.64	€ 163.55	€ 179.66	€ 222.83	€ 250.29	per single trip	100%	118%	174%	191%	237%	266%
	€ 0.38	€ 0.33	€ 0.73	€ 0.68	€ 0.93	€ 1.03	per day per TEU	100%	87%	193%	180%	247%	274%
Voyage Total Cost	€ 185.75	€ 156.54	€ 347.15	€ 271.46	€ 452.33	€ 387.99	per single trip	100%	84%	187%	146%	244%	209%

Bibliography

3sat Mediathek. Güterverkehr: Stau auf der schiene, 2017. URL http://www.3sat.de/mediathek/?obj=70030.

F.F. Achterberg. Trends in schip-naar-kade containerkranen, 2012. URL http://mararchief.tudelft.nl/file/28265/.

Osama Al Enezy, Edwin Van Hassel, Christa Sys, and Thierry Vanelslander. Developing a cost calculation modal for inland navigation. *Research in Transportation Business & Management*, pages 64 – 74, 2017. doi: https://doi.org/10.1016/j.rtbm.2017.02.006. URL https://www.sciencedirect.com/science/article/pii/S2210539516300992.

author = unknown, retrieved 16/07/2018. URL http://www.jimbo.net/CTT/20060907_CTT_grid.jpg.

Daniel Barber and Lisa Grobar. Implementing a statewide goods movement strategy and performance measurement of goods movement in california, 2001. URL https://www.metrans.org/sites/default/files/research-project/99-10_Final_0_0.pdf.

BAST. German field trial with longer trucks, 2016. URL https://www.bast.de/BASt_2017/DE/Verkehrstechnik/Fachthemen/v1-lang-lkw/v-lang-lkw-abschluss-kurz-en.pdf?__blob=publicationFile&v=3.

BDP, retrieved 13/07/2018. URL https://www.bdp-solutions.co.uk/aircargo_handling.php.

M. Beelen. Structuring and modelling decision making in the inland navigation sector, 2011. URL https://www.econbiz.de/Record/structuring-and-modelling-decision-making-in-the-inland-navigation-sector-beel 10009579081.

Jonathan Berk and Peter DeMarzo. *Corporate Finance - Third Edition*. Pearson, 2013. ISBN 9780273792024.

Gust Blauwens. Kosten-batenanalyse van vervoers- en havenprojecten in belgie. pages 169 – 189, 1986.

Gust Blauwens, Peter De Baere, and Eddy Van de Voorde. *Transport Economics - Fourth Edition*. Uitgeverij de Boeck nv., 2010. ISBN 978 90 455 3259 2.

Blommaert, retrieved 12/10/2018. URL https://www.blommaertalu.com/en/products-for-the-shipping-industry/frisian-hatch-covers.

J.U. Brolsma. Rapportage containerhoogtemetingen, 2013. URL https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/rapporten/2014/06/12/rapportage-containerhoogtemetingen/Containerhoogtemetingen+revisie+april+2015.pdf.

Nils A. Bruzelius. Microeconomic theory and generalised cost. *Transportation*, 10:233–245, 1981. ISSN 1572-9435. doi: 10.1007/BF00148460. URL https://doi.org/10.1007/BF00148460.

Thorsten Bätge. Zwei 40-fuß-iso-container (jeweils 2 teu oder 1 feu) oben, darunter zwei 20-fuß-iso-container, 2009. URL https://commons.wikimedia.org/wiki/File:ISO-Container_20ft_40ft_600px_9123.jpg.

Buck Consultants Rotterdam. Een goede toekomst voor het kleine schip: Visie en actieplan, 2008. URL https://informatie.binnenvaart.nl/component/docman/doc_download/19-toekomst-klein-schip-in-de-binnenvaart?Itemid=190.

Bureau Voorlichting Binnenvaart. The blue road map, 2014a. URL https://www.blueroadmap.nl/.

Bureau Voorlichting Binnenvaart. The blue road map, 2014b. URL https://www.bureauvoorlichtingbinnenvaart.nl/assets/images/vaarwegenkaart_2014_groot.jpg.

Bureau voorlichting Binnenvaart. Bruggen en sluizen, year = unknown. URL https://www.bureauvoorlichtingbinnenvaart.nl/assets/images/Over/P1010517.JPG.

Kenneth J. Button. *Transport Economics - 2nd Edition*. Edward Elgar, 1993. ISBN 1 85278 521 7.

C Rail Intermodal. 20ft tanktainer, retrieved 28/02/2018. URL http://www.c-rail-intermodal.co.uk/index.php?route=product/product&product_id=122.

CBRB. Cao loontabel 1 januari 2018, 2018. URL https://www.cbrb.nl/publicaties/35-informatie-voor-werkgevers/1163-loontabel-1-januari-2018.

CBS. Internationale handel en doorvoer; waarde en gewicht, goederenhoofdstukken, 2017. URL https://opendata.cbs.nl/statline/#/CBS/nl/dataset/82007NED/table?ts=1527692814815.

CCNR. Regulations for rhine navigation personnel (rpn), 2016. URL http://www.ccr-zkr.org/files/documents/reglementSTF/stf1_072016_en.pdf.

CCR. Voorjaarszitting 2015 aangenomen besluiten (2015-i), 2015. URL https://www.ccr-zkr.org/files/documents/resolutions/ccr2015_Inl.pdf#search=%2211.01%22.

CCR. Europese binnenvaart: Marktobservatie jaarverslag 2016, 2016. URL https://www.ccr-zkr.org/files/documents/om/om16_II_nl.pdf.

CCR. Europese binnenvaart: Marktobservatie jaarverslag 2017, 2017. URL https://www.ccr-zkr.org/files/documents/om/om17_II_nl.pdf.

CCR EBU ESO Aquapol. Stabiliteitsgids voor het containertransport in de binnenvaart, 2015. URL https://www.ccr-zkr.org/files/documents/guidestabilite/2017_05_Guide_stab_nl.pdf.

EUROPEAN CONFERENCE OF MINISTERS OF TRANSPORT CEMT. Resolution no. 92/2 on new classification of inland waterways, 1992. URL https://www.itf-oecd.org/sites/default/files/docs/wat19922e.pdf.

CESNI. Europese standaard tot vaststelling van de technische voorschriften voor binnenschepen, 2015. URL https://www.ccr-zkr.org/files/documents/cesni/ES_TRIN_nl.pdf.

Chassis King. Corner castings / corner fittings, retrieved 27/02/2018. URL http://www.chassisking.com/products/parts-and-accessories/corner-castings-corner-fittings/.

Chemical Pollution. Arrangement of containers, retrieved 28/02/2018. URL http://www.chemical-pollution.com/en/shipping/ship-types.php.

Rejo Chrétien, Johan & Fresh. Belgische transporteurs willen filekosten doorberekenen aan klant, 2018. URL http://www.agf.nl/artikel/167658/Belgische-transporteurs-willen-filekosten-doorberekenen-aan-klant.

Ciciban. Wasserwegenetz, deutschland und angrenzende, year = unknown. URL https://commons.wikimedia.org/wiki/File:Wasserwege.svg.

Contargo. Information brochure 'low water', 2017. URL https://www.contargo.net/assets/pdf/Kleinwasser_Info-2017-EN.pdf.

Contargo. "baf-tarif", retrieved table for June 2018 on 03/05/2018. URL https://www.contargo.net/nl/goodtoknow/baf/staffel_next/.

Conveyor Handling Company, retrieved 16/07/2018. URL http://conveyorhandling.com/products/conveyors/.

Covadem. Shipping made smarter, consulted on 18/02/2018. URL https://www.covadem.org/home.

D Design. Intermodal container stack, 2014. URL https://commons.wikimedia.org/wiki/File:Container_Stacking.jpg.

Romeo Danielis and Edoardo Marcucci. Attribute cut-offs in freight service selection. *Transportation Research Part E: Logistics and Transportation Review*, 43(5):506 – 515, 2007. doi: https://doi.org/10.1016/j.tre.2005.10.002. URL http://www.sciencedirect.com/science/article/pii/S1366554506000317.

Anne De Boer. Containerschip vast onder brug burgum, 2011. URL https://www.schuttevaer.nl/nieuws/actueel/nid16853-containerschip-vast-onder-brug-burgum.html.

DG MOVE. Update of the handbook on external costs of transport, 2014. URL https://ec.europa.eu/transport/sites/transport/files/handbook_on_external_costs_of_transport_2014_0.pdf.

Bas Dijkhuizen. Congestie haven rotterdam is vooral een supply chain probleem, 2017a. URL https://www.logistiek.nl/distributie/nieuws/2017/12/congestie-haven-rotterdam-is-vooral-een-supply-chain-probleem-101161068.

Bas Dijkhuizen. Ruzie in de rotterdamse haven door falende ketenregie, 2017b. URL https://www.logistiek.nl/ketensamenwerking/nieuws/2017/10/heibel-de-rotterdamse-haven-door-gebrekkige-ketensamenwerking-101159195.

Duisport. An efficient transport concept is the best way, 2018. URL http://www.duisport.de/dienstleistungen/verkehr-und-logistische-dienstleistungen/intermodale-transportkonzepte.html.

BVB Dutch Inland Navigation Information Agency. The power of inland navigation, 2017. URL https://www.bureauvoorlichtingbinnenvaart.nl/assets/files/WaardeTransport_spreads-UK.pdf.

logistics 4.0 Ekol. The intermodal experience, retrieved 22/02/2018. URL http://www.ekol.com/en/services/freight/intermodal/.

European Commission; Directive of the European Parliament and of the Council. Technical requirements for inland waterway vessels (2006/87/ec), 2006. URL https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32006L0087.

European Court of Auditors. Rail freight transport in the eu: still not on the right track, 2016. URL http://ec.europa.eu/transport/modes/road/events/doc/2009_06_24/2009_gigaliners_workshop_acea.pdf.

Evergreen Marine Corp. Ltd. Container specifications, retrieved 27/02/2018. URL https://www.evergreen-marine.com/tei1/jsp/TEI1_Containers.jsp.

Evofenedex. Dossier vervoer gevaarlijke stoffen over de weg | adr, retrieved 05/03/2018. URL https://www.evofenedex.nl/kennis/gevaarlijke-stoffen/adr-wegvervoer-gevaarlijke-stoffenl.

FD. Pionier loodst binnenvaart nieuw elektrisch tijdperk in, 2018. URL https://fd.nl/morgen/1243299/pionier-loodst-binnenvaart-nieuw-elektrisch-tijdperk-in.

found on MarineTraffic.com. Camaro, year = unknown. URL https://www.marinetraffic.com/en/ais/details/ships/shipid:236256/mmsi:244650847/vessel:CAMARO.

Freights.EU. Maximum vehicle gross weight in european countries, 2014. URL http://freights.eu/article/regulations/logistics/transport/maximum-vehicle-gross-weight-european-countries.html.

FUWA. Marine shipping standard specifications: Iso/tc-104; tct cert; csc cert., retrieved 28/02/2018. URL http://www.intermodal-asia.com/products/20ft-reefer-container.

Scheepswerf Gebr. Kooiman. Bnr 172 - veerhaven x – orka, year = unknown. URL https://kooimanmarinegroup.nl/bnr-172-veerhaven-x---orka.html.

Lavinia Graßer, Silke & Haane. Verkehr kostet deutsche wirtschaft 33 milliarden euro im jahr 2030, 2014. URL http://inrix.com/press-releases/verkehr-kostet-deutsche-wirtschaft-33-milliarden-euro-im-jahr-2030/.

Alexander Grey. The generalised cost dilemma. 1820:261 – 280, 1978.

Monica Grosso. Improving the competitiveness of intermodal transport: applications on european corridors, 2011. URL http://hdl.handle.net/10067/934530151162165141.

Thor-Erik Sandberg Hanssen, Terje Andreas Mathisen, and Finn Jørgensen. Generalised transport costs in intermodal freight transport. *Procedia - Social and Behavioural Sciences*, pages 189 – 200, 2012. doi: https://doi.org/10.1016/j.sbspro.2012.09.738. URL https://www.sciencedirect.com/science/article/pii/S1877042812042000.

Hapag-Lloyd AG. Container specifications, 2016. URL https://www.hapag-lloyd.com/content/dam/website/downloads/press_and_media/publications/15211_Container_Specification_engl_Gesamt_web.pdf.

Tessa Heerschop and Erik Van Huizen. Schreeuwend tekort aan schippers en stuurlieden, 2017. URL https://www.schuttevaer.nl/nieuws/varend-bestaan/nid27083-schreeuwend-tekort-aan-schippers-en-stuurlieden.html.

R.G. Hekkenberg. Inland ships for efficient transport chains, 2013. URL https://repository.tudelft.nl/islandora/object/uuid:f2ead20f-80b5-4d92-818f-7586c7b85f76?collection=research.

J.A.C. Hekman. Key design factors maritime container terminals, 2001. URL http://maritimetechnology.wbmt.tudelft.nl/catalogue/entries/20707/d.

S. Hengst. Binnenvaart in beeld, 1995.

HSS, 2017. URL http://www.hsssearch.co.uk/page_837565.asp.

International Maritime Organization. Solas container mass verification requirements, retrieved 05/03/2018. URL http://www.imo.org/en/MediaCentre/HotTopics/container/Pages/default.aspx.

J.A. Keuning. Stabiliteit mt526, 2013.

Nam Seok Kim and Bert Van Wee. The relative importance of factors that influence the break-even distance of intermodal freight transport systems. *Journal of Transport Geography*, 19(4):859 – 875, 2011. ISSN 0966-6923. doi: https://doi.org/10.1016/j.jtrangeo.2010.11.001. URL http://www.sciencedirect.com/science/article/pii/S096669231000181X.

Hans Klein Woud and Douwe Stapersma. *Design of Propulsion and Electric Power Generation Systems*. IMarEST, 2008. ISBN 1-902536-47-9.

Koch Adviesgroep, retrieved 02/07/2018. URL http://ngict.eu/.

J.W. (Rob) Konings. Intermodal barge transport: Network design, nodes and competitiveness, 2009. URL https://repository.tudelft.nl/islandora/object/uuid:ff6f5f10-2acc-43fb-9474-5317b0988bdd/?collection=research.

Rob Konings. Network design for intermodal barge transport. 1820, 01 2003.

Carl Koopmans, Wim Groot, Pim Warffemius, Jan Anne Annema, and Sascha Hoogendoorn-Lanser. Measuring generalised transport cost as an indicator of accessibility changes over time. *Transport Policy*, pages 154 – 159, 2013. doi: https://doi.org/10.1016/j.tranpol.2013.05.005. URL https://www.sciencedirect.com/science/article/pii/S0967070X13000875.

Rolf Koppen. Duisport increases total handling volume to 65 million tons, 2014. URL http://bulk-distributor.com/wp-content/uploads/2014/12/duisport_Duisburg-Intermodal-terminal-DIT_-Rolf-K%C3%B6ppen.jpg.

Frederic Lambert. A look at daf's new all-electric truck with a 170 kwh battery pack, 2018. URL https://electrek.co/2018/05/16/daf-all-electric-truck-battery-pack/.

Stefan Larsson. Weight and dimensions of heavy vehicles as established by directive 96/53/ec and the european modular system (ems), 2009. URL http://ec.europa.eu/transport/modes/road/events/doc/2009_06_24/2009_gigaliners_workshop_acea.pdf.

Marc Levinson. *The Box: How the Shipping Container Made the World Smaller and the World Economy Bigger.* Princeton Univertisty Press, 2010. ISBN 9781400828586. URL https://books.google.nl/books?id=ljHq6-HnW1QC.

Liebherr. Port equipment, retrieved 12/04/2018. URL https://www.liebherr.com/en/rou/products/maritime-cranes/port-equipment/port-equipment.html.

H. Ligteringen and H. Velsink. *Ports and Terminals CIE4330/CIE5306.* TU Delft, 2012.

Lloyd's Register and The Standard. A master's guide to: Container securing 2nd edition, 2012. URL http://www.standard-club.com/media/24168/amastersguidetocontainersecuring2ndedition-3.pdf.

Rico Luman. Transport en logistieksector houdt de snelheid erin, 2017. URL https://www.ing.nl/zakelijk/kennis-over-de-economie/uw-sector/outlook-2018/transport-en-logistiek.html.

Cathy Macharis and Alain Verbeke. *Intermodaal binnenvaartvervoer. Economische en strategische aspecten van het intermodaal vervoer in Vlaanderen.* Garant, 2004. ISBN 90-441-1566-9. Garant, Antwerpen.

Ald Makkum. kruiplijncoaster vita nova, later renamed to mike, 2013. URL http://www.ald-makkum.nl/amelsdetail.php?id_main=216.

Container Management, retrieved 12/04/2018. URL http://container-mag.com/2017/07/26/hybrid-reachstacker-operation-duisburg/.

Roger McGough, Graeme McAulay, and Dominic Crossley-Holland. The box that changed britain (documentary), 2010. URL http://www.bbc.co.uk/programmes/b00scpzn.

Fabien Mercier, Hokuto Hotsuka, and Filipe Silva. Steel market developments q4 2017, 2018. URL http://www.oecd.org/sti/ind/steel-market-developments-Q42017.pdf.

Mercurius schipping group. Start-up binnenvaart, 2018.

Mercurius Shipping Group, retrieved 12/07/2018. URL https://www.mercurius-group.nl/wp-content/uploads/2016/06/1-30.jpg.

Moscow Cargo, retrieved 02/08/2018. URL https://moscow-cargo.com/index.php/en/press-center/30-news-corporate/94-champ350.

Multimodaal Brabant. http://www.mcabrabant.nl/9-nieuws/98-40-miljoen-minder-vrachtautokilometers-dankzij-multimodaal-vervoer-in-brabant, retrieved 12/04/2018. URL http://www.mcabrabant.nl/9-nieuws/98-40-miljoen-minder-vrachtautokilometers-dankzij-multimodaal-vervoer-in-brabant.

R. Naicker and D. Allopi. Evaluating straddle carriers and rubber tyred gantrys, 2015. URL http://ijiset.com/vol2/v2s5/IJISET_V2_I4_18.pdf.

Folkert Nicolai. Veel bedrijven overwegen overstap van binnenschip naar truck, 2017. URL https://www.nieuwsbladtransport.nl/wegvervoer/2017/10/05/veel-bedrijven-overwegen-overstap-van-binnenschip-naar-truck/.

NOS economie redactie. Vrachtvervoerders lijden 1 miljard euro schade door files, 2016. URL https://nos.nl/artikel/2206504-vrachtvervoerders-lijden-1-miljard-euro-schade-door-files.html.

Panama Canal Authority, retrieved 02/08/2018. URL http://www.pancanal.com/eng/projects/locomotive.html.

(Formerly known as NEA) Panteia. Factorkosten van het goederenvervoer: een analyse van de ontwikkeling in de tijd, 2004. URL https://www.google.nl/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwiAh9yL45rMAhXC6xQKHV2QBIAQFggcMAA&url=http%3A%2F%2Fpublicaties.minienm.nl%2Fdownload-bijlage%2F56319%2Ffactorkosten.pdf&usg=AFQjCNEo-b6ldk-z2BW3LT5xdVDbfEqtkA.

Enrico Pastori. Modal share of freight transport to and from eu ports, 2015. URL http://www.europarl.europa.eu/RegData/etudes/STUD/2015/540350/IPOL_STU(2015)540350_EN.pdf.

InCom Working Group 09 PIANC. Standardization of inland waterway dimensions, 1990. URL http://www.pianc.org/edits/articleshop.php?id=1000091.

InCom Working Group 20 PIANC. Factors involved in standardising the dimensions of class vb inland waterways (canals), 1999. URL http://www.pianc.org/edits/articleshop.php?id=1000201.

Planco Consulting GmbH and Bundesanstalt für Gewässerkunde. Economical and ecological comparison of transport modes: Road, railways, inland waterways, 2007. URL http://www.ebu-uenf.org/fileupload/SummaryStudy_engl.pdf.

Platts Bunkerworld. Fuel prices, wti price history, 2018. URL http://www.bunkerworld.com/prices/crude/.

Port of Amsterdam. Containertarief, 2018. URL https://www.portofamsterdam.com/nl/scheepvaart/binnenvaart/binnenhavengeld#bhg1.

Port of Rotterdam. Binnenvaart is milieuvriendelijk alternatief voor vrachtverkeer, retrieved 15/02/2018. URL https://www.maasvlakte2.com/nl/index/show/id/242/de-binnenvaart.

Promotie Binnenvaart Vlaanderen. Waterwegen volgens cemt-klasse en sluizen, year = unknown. URL https://www.binnenvaart.be/images/kaarten-CEMT/index.html.

W.C.A. Rademaker. Container terminal automation; feasibility of terminal automation for mid-sized terminals, 2007. URL https://repository.tudelft.nl/islandora/object/uuid%3Aa8cc2962-c6c1-4695-bc24-2f2a7f27a2dd.

Railwaypro. Itf 2017: Longer freight trains could be operating on the rhine-alpine rail freight corridor, 2017. URL https://www.railwaypro.com/wp/itf-2017-longer-freight-trains-operating-rhine-alpine-rail-freight-corridor/.

Rebelgroup, BMT surveys, and Eric Van Hooydonk Advocaten. Concurrentiepositie binnenvaart, 2015. URL http://www.itb-info.be/files/cms1/eindrapport-binnenvaart-final.pdf.

Rijksoverheid. Rid 2017, 2017. URL https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/publicaties/2015/05/21/rid/RID+2017+definitief.PDF.

Rijksoverheid. Nieuwe beveiliging van het spoor (ertms), retrieved 21/06/2018. URL https://www.rijksoverheid.nl/onderwerpen/spoor/veiligheid-op-het-spoor/spoorbeveiliging-ertms.

Rijkswaterstaat. Richtlijnen vaarwegen 2017, 2017a. URL https://staticresources.rijkswaterstaat.nl/binaries/richtlijnen-vaarwegen-2017_tcm21-127359.pdf.

Rijkswaterstaat. Veelgestelde vragen. 2017b.

Dienst Verkeer en Scheepvaart (DVS) Rijkswaterstaat. Scheepvaartinformatie hoofdvaarwegen, 2009. URL https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/rapporten/2009/08/01/scheepvaartinformatie-hoofdvaarwegen-editie-2009/scheepvaartinformatie-20hoofdvaarwegen-20editie-202009.pdf.

Steve Ringman, 2005. URL http://old.seattletimes.com/html/businesstechnology/2002592235_port30.html.

Jean-Paul Rodrigue. Reefers in north american cold chain logistics: Evidence from western canadian supply chains, 2014. URL http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.731.3967&rep=rep1&type=pdf.

B.J.C.M. Rutten. On medium distance intermodal rail transport: A design method for a road and rail inland terminal network and the dutch situation of strong inland shipping and road transport modes, 1995. URL uuid:49f9b794-5a59-4d7d-abea-44da79ba9d0f.

Y.A. Saanen. An approach for designing robotized marine container terminals, 2004. URL https://repository.tudelft.nl/islandora/object/uuid:62f69bbe-df26-4570-a490-cd10e038cb92/datastream/OBJ/download.

A Schroten, H.P. Van Essen, S.J. Aarnink, E Verhoef, and J. Knockaert. Externe en infrastructuur kosten van verkeer, 2014. URL https://www.ce.nl/publicaties/download/1658.

Leo Schuitemaker. Zie hoe het achterschip van de duw'bak' aangepast is aan het voorschip van het duwschip., 2007. URL http://www.debinnenvaart.nl/binnenvaarttaal/afbeeldingen/schepen/vrachtschepen_nieuw/koppelverband/495vision2324592volkeraksluizen07102007leo110b.jpg.

photographer: Joerg Seyler. Rhine forest - imo 7125706, 1998. URL http://www.shipspotting.com/gallery/photo.php?lid=1904469.

Martijn Smid, Sander Dekker, and Bart Wiegmans. Modelling the cost sensitivity of intermodal inland waterway terminals: A scenario based approach, 2016. URL https://www.sciencedirect.com/science/article/pii/S0965856416000069.

R.T.M. Smokers and W.G. Rozendaal. De invloed van congestie op brandstofverbruik en emissies van vrachtwagens, 1998. URL http://publications.tno.nl/publication/34613642/z5P6wA/98.OR.VM.029.1-RSM.pdf.

M. Stopford. *Maritime Economics 3rd edtion*. Routledge, Abindon, Oxon, 2009. ISBN 9780415275576 (hbk).

Translink, retrieved 12/04/2018. URL http://translinkbv.nl/translinkbv.nl/over-ons/.

TU Delft & Nesec B.V. Ship finance, 2014.

UNECE. European agreement concerning the international carriage of dangerous goods by inland waterways, retrieved 05/03/2018. URL https://www.unece.org/trans/danger/publi/adn/adn_e.html.

unknown. Koppelverband roxy, 2007. URL https://upload.wikimedia.org/wikipedia/commons/3/36/Roxy_KV.jpg.

Wouter Van der Geest, Rob De Leeuw van Weenen, Menno Menist, Arnaud Burgess, Bastiaan Van Berne, and Inge Mijnders. Toekomst van goederenvervoer over water in noord-holland, 2018. URL https://www.panteia.nl/onderzoeken/panteia-initieert-vaarwegenbeleid-provincie-noord-holland/.

E. Van der Maaten. Barge terminal mtc valburg, 2002. URL https://repository.tudelft.nl/islandora/object/uuid:9b85a239-ce4d-4fd4-b9e1-6142c9d956e0.

Sander Van der Meulen and Wouter Van der Geest. Kostenbarometer + binnenvaart + 062016, 2016. URL http://publicaties.minienm.nl/download-bijlage/56319/factorkosten.pdf.

Sander Van der Meulen, Wouter Van der Geest, and Rob De Leeuw van Weenen. Middellange termijn prognoses voor de binnenvaart 2018-2022, 2018. URL https://www.panteia.nl/onderzoeken/middellange-termijn-prognoses-ladingvolume/#download.

B. Van der Rakt. Voorontwerp afhandeling wegcontainers, 2002. URL http://pubs.iids.org/index.php/publications/show/1137.

J.C.M. Van Dorsser. Very long term development of the dutch inland waterway transport system, 2015. URL https://repository.tudelft.nl/islandora/object/uuid:d9cd85d4-2647-49e4-8e7c-df66e27681d3/?collection=research.

Erik Van Huizen. Afgestudeerden beginnen op kleinste binnenvaartschip, 2014. URL http://www.debinnenvaart.nl/binnenvaarttaal/afbeeldingen/onderdelen/onderdelen-duwvaart/Koppelsysteem_GRESVENIC06002415_mvs_Volkeraksluizen_060808LeoS_013.jpg.

T.G.A. Van Kester. Exploitatiewijzen en bemanningseisen in de binnenvaart, 2014a. URL https://www.cbrb.nl/nieuws/documenten/doc_download/1425-exploitatiewijzen-en-bemanningseisen-in-de-binnenvaart-samenvatting-onderzoeksrapport.

T.G.A. Van Kester. Exploitatiewijzen en bemanningseisen in de binnenvaart, 2014b. URL https://www.cbrb.nl/nieuws/documenten/doc_download/1425-exploitatiewijzen-en-bemanningseisen-in-de-binnenvaart-samenvatting-onderzoeksrapport.

Bert Van Leeuwen. Intermodal container leasing, 2018. URL http://www.world-leasing-yearbook.com/intermodal-container-leasing/.

Bart Van Riessen. "synchromodaal is beter voor binnenvaart", 2018. URL http://www.binnenvaartkrant.nl/nieuws/nieuwsitem/synchromodaal-is-beter-voor-binnenvaart/.

Maurits Van Schuylenburg and Linda Borsodi. Container transferium rotterdam: An innovative logistic concept, 2010. URL https://repository.tudelft.nl/islandora/object/uuid%3Af8b2b14e-1f04-457a-92e8-43ba90573f1b?collection=research.

Natascha Van Staalduinen. The future challenge for inland terminal operators in the netherlands, 2014. URL https://thesis.eur.nl/pub/15825/MA-thesis-N-van-Staalduinen.pdf.

Hugo Van Vondelen. Betuweroute : A new freight railway from rotterdam harbour to the german border, 2010. URL http://www.intermodale24-rail.net/linee/Betuwelijn-ENG.html.

B. Van Wee and J.A. Annema. *Verkeer en vervoer: een introductie*. Uitgeverij coutinho, Bussum, The Netherlands, 2014. ISBN 9789046904237.

E.J.A. Van Zijderveld. A structured terminal design method: With a focus on rail container terminals, 1995. URL https://repository.tudelft.nl/islandora/object/uuid:842cf157-c54c-48c9-856b-cc6b3e585836?collection=research.

Via Donau. Manual on danube navigation, 2007.

Watertruck+. website, 2018. URL http://www.watertruckplus.eu/.

Bart Wiegmans and Rob Konings. Intermodal inland waterway transport: Modelling conditions influencing its cost competitiveness. *The Asian Journal of Shipping and Logistics*, 2015. doi: https://doi.org/10.1016/j.ajsl.2015.06.006. URL https://www.sciencedirect.com/science/article/pii/S2092521215000346.

Marc Wiget, Yannick & Fehr. So viel kosten staus jährlich, 2016. URL https://www.derbund.ch/schweiz/standard/so-viel-kosten-staus-jaehrlich/story/26085971.

N. Wijnolst, H.B. Van der Hoeven, C.J. Kleijwegt, and A Sjöbris. Innovation in shortsea shipping, 1993. URL https://repository.tudelft.nl/islandora/object/uuid:6649f533-6700-4c81-bd54-817a19aa850b/datastream/OBJ.

World Bank Group. Commodity markets outlook, 2018. URL http://pubdocs.worldbank.org/en/271041524326092667/CMO-April-2018-Full-Report.pdf.

World Shipping Council. Container supply review, 2011. URL http://www.worldshipping.org/public-statements/2011_container_supply_review_final.pdf.

WSV. Schleuse münster dek km 71,50, 2018. URL http://www.wsa-rheine.de/wasserstrassenbereich/dek/schleusen/schleuse_muenster/index.html.

WWasser, based on ICPR & RWS publications. Rhine course and river system, place names in english, 2013. URL https://commons.wikimedia.org/wiki/File:Flusssystemkarte_Rhein_04.jpg.

Elisabeth Zehendner and Dominique Feillet. Benefits of a truck appointment system on the service quality of inland transport modes at a multimodal container terminal. *European Journal of Operational Research*, 235 (2):461–469, 2014. doi: https://doi.org/10.1016/j.ejor.2013.07.005. URL https://www.sciencedirect.com/science/article/pii/S0377221713005675.

Xiaoju Zhang, Qingcheng Zeng, and Zhongzhen Yang. Optimization of truck appointments in container terminals, 2018. URL https://link.springer.com/content/pdf/10.1057%2Fs41278-018-0105-0.pdf.

Roel Ziel. Feasibility study of an inland waterway container terminal in business park de mars, zutphen, 2017. URL https://repository.tudelft.nl/islandora/object/uuid%3A9f26c36c-9e14-4f14-b7d3-17f635326005.