Enhancing the competitiveness of inland waterway transport: A multi-methodological approach applied to port barge congestion and urban areas.

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Abbreviations

Abbreviation	Definition
CITBO	Corporation Inland Tanker Barge Owners
AAWA	Advanced Autonomous Waterborne Applications
ABM	Agent-Based Model
AGV	Automated Guided Vehicles
AIS	Automatic Identification System
AL	Autonomy Level
AOS	Automated Operation System
APCS	Antwerp Port Community System
APICS	Antwerp Port Information Control System
ASTRA	Assessment of Transport Strategies
B2B	Business to Business
B2C	Business to Customers
BCS	Barge Coordination System
BLL	Blue Line Logistics
BTS	Barge Traffic System
CBA	Cost Benefit Analysis
CBP	Central Booking Platform
CBPM	Central barge planning and monitoring
CCNR	Central Commission for Navigation on the Rhine
CEMT	Conferentie van Europese Ministers van Transport
CH_4	Methane
CO_2	Carbon dioxide

COVID	Corona Virus Disease
CP	Constraint Programming
CPI	Consumer Price Index
DWT	Dead Weight Tonnage
EAT	Earnings after Tax
EBITDA	Earnings before Interest, Tax, Depreciation, and Amortization
EBT	Earnings before Tax
ENPV	Economic Net Present Value
ETA	Estimated Time of Arrival
ETD	Estimated Time of Departure
EUR	Euro
FMCG	Fast-Moving Consumer Goods
FNPV	Financial Net Present Value
FTL	Full Truck Load
GDP	Gross Domestic Product
GPS	Global Positioning System
HGV	Heavy Goods Vehicles
ILP	Integer Linear Programming
IRR	Internal Rate of Return
IT	Information Technology
IWT	Inland Waterway Transport
IWV	Inland Waterborne Vessels
KCE	The Belgian Health Care Knowledge Centre
KPI	Key Performance Index
LGV	Light Good Vehicles

LIDAR	Light Detection and Ranging
LSP	Logistics Service Providers
LTL	Less than Full Truckload Delivery
MIP	Mixed Integer Programming
MMT	Modular Mobile Terminal
MPET	MSC PSA European Terminal
MUNIN	Maritime Unmanned Navigation through Intelligence in Networks
N_2O	Nitrous Oxide
NBB	National Bank of Belgium
NH3	Ammonia
NMVOC	Non-Methane Volatile Organic Compounds
NOVIMOVE	Novel Inland Waterway Transport Concepts for Moving Freight Effectively
NOX	Nitrogen Oxide
NPV	Net Present Value
NUTS	Nomenclature of Territorial Units for Statistics
NW	North Western
OD	Origin-Destination
OECD	Organization for Economic Cooperation and Development
PBP	Pay Back Period
PBS	Premium Barge Service
PM	Particulate Matter
PSB	Pallet Shuttle Barge
PV	Present Value
SCBA	Social Cost Benefit Analysis
SFC	Specific Fuel Consumption

SNPV	Social Net Present Value
SO_2	Sulfur Dioxide
STATBEL	Statistics Belgium
SWOT	Strength, Weakness, Opportunity, and Threat
TEU	Twenty-foot Equivalent Unit
TLC	Total Logistics Cost
UFD	Urban Freight Distribution
UWB	Ultra Wide Band
VOC	Volatile Organic Compounds
WACC	Weighted Average Cost of Capital
WTT	Well-to-Tank

Summary of the thesis

Inland shipping could provide a competitive and more sustainable mode of transport in Europe, as it could take advantage of this region's large and dense inland waterway network. However, this is not the case due to the different challenges faced in the Inland Waterway Transport (IWT) sector. Furthermore, there have been growing concerns about the negative societal impact of road transport within dense cities and urban areas. This brings an opportunity for inland shipping to utilize the dense IWT networks that connect to the city centers to use last-mile transport to the urban areas. By doing this, inland shipping can offer a better alternative to road transport and take over some urban freight flows, enhancing its competitiveness and maximizing its underutilized capacities.

The rationale of this thesis stems from the need to enhance and strengthen the competitiveness of IWT. IWT competitiveness in this research is a multifaceted concept involving a range of factors that affect the ability to transport cargo to shippers efficiently and effectively. This includes the ability of IWT to provide reliable, efficient, and cost-effective transportation services compared to other transport modes (mainly road transport). Thus, enhancing competitiveness is examined in two stages: the IWT port-hinterland container transport (specifically focusing on port barge operations) and the IWT urban freight transport. These two stages are examined due to the major issues they generate in the hinterland supply chain between the seaports and urban areas, such as barge congestion in seaport operations and the increasing negative externalities of urban freight delivery with trucks.

Based on this, three main research questions were identified and addressed in the thesis. These are:

1. What are the main challenges of container barge operations in seaports in North-Western Europe?
2. How can these challenges be addressed?
3. Is it possible to deploy (small) inland vessels for urban freight use from a private and welfare viewpoint?

These questions were answered through a multi-methodological approach. A quantitative survey was used to answer the first research question. In contrast, multiple quantitative techniques, such as the agent-based and economic assessment models, answered the second research question. Finally, a social cost-benefit (SCBA) model answered the third research question.

The main answer to the first research question reveals that the challenges of container IWT are interrelated and can be categorized into three main themes: handling, coordination, and flexibility. These three themes can further be broken down into specific problems. These include the interference of deep-sea vessels, lack of dedicated barge spaces, small call sizes, poor planning, fixed slots, flexible schedules, and low service levels due to port congestion. The analysis further reveals that while some problems could be addressed by innovation within the container IWT sector, others can only be addressed through a change in mentality within the industry. Based on this finding, the thesis focuses only on problems that can be addressed via innovation within the sector, such as barge handling in sea terminals, small call sizes, dedicated barge space, planning, and barge slots/scheduling in sea terminals.

The answer to the second research question suggests that dedicated barge space could solve container barge challenges in seaport operations. In this sense, if the terminals can create a dedicated handling space and invest in suitable infrastructures for the container barges, it could significantly reduce the waiting time of the barges and ensure that they do not spend an extended period at the terminals. With this, there could be a shorter lead time leading to more reliability and the enhancement of the logistical operations.

Based on the above, a further analysis was conducted to examine the economic feasibility of a Modular Mobile Terminal (MMT) as a potential concept for the dedicated barge space solution for port-barge operation. This was analyzed for the Port of Antwerp-Bruges (PoAB) and the Port of Rotterdam (PoR). The overall conclusion of the analysis suggests that the MMTs are most suitable for regions and vessels with small cargo volumes and can deal with the effects of a high seasonality pattern (caused, for example, by a disruption). Regarding the specific ports, the study indicates that four MMTs would be optimal for PoR, while two MMTs would optimally be installed in PoAB.

The main answers to the third research question reveal that the small vessel concept for urban freight delivery appears feasible for the vessel owner both from the private and the welfare point of view. A possible reason is a short distance from the pick-up to the drop-off point in the vessel trajectory. Regarding the Total Logistics Cost (TLC), the analysis reveals that the small vessel concept is the cheapest option for low-value goods from the private point of view, while trucks remain the cheapest option for high-value goods. However, when internalizing the external costs, the small vessel option offers the cheapest option for all categories of goods for the cargo owners from the welfare viewpoint.

Samenvatting van het proefschrift

De binnenvaart is een concurrentiële vervoerswijze in Europa die kan profiteren van het grote en dichte netwerk van binnenwateren in deze regio. Echter zou het concurrentievermogen van de binnenvaart groter kunnen zijn als het niet geconfronteerd zou zijn met verschillende uitdagingen. Bovendien groeit de bezorgdheid over de negatieve maatschappelijke gevolgen van het wegvervoer in dichtbevolkte steden en stedelijke gebieden. Dit biedt de binnenvaart de mogelijkheid gebruik te maken van de dichte binnenvaartnetwerken die aansluiten op de stadscentra om gebruik te maken van "last mile" vervoer naar de stedelijke gebieden. Op die manier kan de binnenvaart een beter alternatief bieden voor het wegvervoer en lading transporten naar stedelijke gebieden, waardoor haar concurrentievermogen toeneemt en haar onderbenutte capaciteit wordt gemaximeerd.

De grondgedachte van dit proefschrift komt voort uit de noodzaak om het concurrentievermogen van de binnenvaart te vergroten en te versterken. Het concurrentievermogen van de binnenvaart is in dit onderzoek een veelzijdig concept met een reeks factoren die van invloed zijn op het vermogen om vracht efficiënt en effectief te vervoeren. Dit omvat het vermogen van de binnenvaart om betrouwbare, efficiënte en kosteneffectieve vervoersdiensten te leveren in vergelijking met andere vervoerswijzen (hoofdzakelijk wegvervoer). De verbetering van het concurrentievermogen wordt dus in twee fasen onderzocht: het binnenvaartcontainervervoer tussen een zeehaven en haar achterland en het stedelijk goederenvervoer met gebruik van binnenvaart. Deze twee fasen worden onderzocht vanwege de belangrijke problemen die zij ondervinden, zoals de congestie van de binnenvaart in de zeehavenactiviteiten en de toenemende negatieve externe effecten van de levering van goederen in de stad met vrachtwagens.

Op basis hiervan werden drie onderzoeksvragen geïdentificeerd dit in proefschrift behandeld worden. Deze zijn:

1. Wat zijn de belangrijkste uitdagingen van containerbinnenvaartoperaties in zeehavens in Noordwest-Europa?
2. Hoe kunnen deze uitdagingen worden aangepakt?
3. Is het mogelijk om (kleine) binnenschepen in te zetten voor stedelijk vrachtgebruik vanuit een particulier en welzijnsoogpunt?

Deze vragen werden beantwoord via een multi-methodologische aanpak. Voor het beantwoorden van de eerste onderzoeksvraag is gebruik gemaakt van een kwantitatieve enquête. De tweede onderzoeksvraag werd daarentegen beantwoord met meerdere kwantitatieve methodes, zoals de agent-based- en economische evaluatiemodellen. Ten slotte beantwoordde een sociaal kosten-batenmodel (MKBA) de derde onderzoeksvraag.

Uit het belangrijkste antwoord op de eerste onderzoeksvraag blijkt dat de uitdagingen van de containerbinnenvaart onderling samenhangen en kunnen worden ingedeeld in drie hoofdthema's: behandeling, coördinatie en flexibiliteit. Deze drie thema's kunnen verder worden opgesplitst in specifieke problemen. Deze omvatten de inmenging van diepzeeschepen, het gebrek aan speciale binnenvaartruimten, kleine aanloophoeveelheden, slechte planning, vaste slots, flexibele schema's en lage dienstverleningsniveaus ten gevolge van havencongestie. Uit de analyse blijkt verder dat sommige problemen weliswaar kunnen worden aangepakt door innovatie binnen de containerbinnenvaartsector, maar dat andere alleen kunnen worden aangepakt door een mentaliteitsverandering binnen de sector. Op basis van deze bevinding richt het proefschrift zich alleen op problemen die kunnen worden aangepakt door innovatie binnen de sector, zoals de afhandeling van binnenvaartschepen in zeehaventerminals, kleine call sizes, speciale ruimte voor binnenvaartschepen, planning en binnenvaartslots/planning in zeehaventerminals.

Het antwoord op de tweede onderzoeksvraag suggereert dat specifieke ruimte voor de binnenvaart een oplossing zou kunnen bieden voor de problemen met de containerbinnenvaart in zeehavens. Als de terminals een speciale behandelingsruimte kunnen creëren en kunnen investeren in geschikte infrastructuur voor de containerbinnenvaart, kan dit de wachttijd van de binnenvaart aanzienlijk verkorten en ervoor zorgen dat deze niet te lang bij de terminals blijft. Hierdoor zou de doorlooptijd korter kunnen worden, wat de betrouwbaarheid en de verbetering van de logistieke operaties ten goede zou komen.

Op basis van het bovenstaande werd een verdere analyse uitgevoerd om de economische haalbaarheid te onderzoeken van een modulaire mobiele terminal (MMT) als een potentieel concept voor de oplossing van specifieke binnenvaartruimte voor haven-binnenvaartoperaties. Dit werd geanalyseerd voor de haven van Antwerpen-Brugge (PoAB) en de haven van Rotterdam (PoR). De algemene conclusie van de analyse luidt dat de MMT's het meest geschikt zijn voor regio's en schepen met kleine ladingvolumes en de effecten van een hoog seizoenspatroon kunnen opvangen. Wat de specifieke havens betreft, geeft de studie aan dat vier MMT's optimaal zouden zijn voor de haven van Rotterdam (PoR), terwijl twee MMT's optimaal zouden zijn voor de haven Antwerpen-Brugge (PoAB).

Uit de belangrijkste antwoorden op de derde onderzoeksvraag blijkt dat het concept van kleine schepen voor de levering van stadsvracht haalbaar lijkt voor de scheepseigenaar, zowel vanuit privé- als vanuit welzijnsoogpunt. Een mogelijke reden hiervoor is de korte afstand tussen het ophaal- en het afleverpunt in het scheepstraject. Wat de totale logistieke kosten (TLC) betreft, blijkt uit de analyse dat het kleine schip vanuit particulier oogpunt de goedkoopste optie is voor goederen met een lage waarde, terwijl vrachtwagens de goedkoopste optie blijven voor goederen met een hoge waarde. Wanneer echter de externe kosten worden geïnternaliseerd, biedt de optie van het kleine schip voor alle goederencategorieën de goedkoopste optie voor de eigenaars van de vracht uit welzijnsoogpunt.

Chapter 1 - Introduction

1.1 Introduction

There has been growing recognition of Inland Waterway Transport's (IWT) potential in recent years to provide a viable and competitive alternative to road and rail transportation. This transport mode has been identified as a possible sustainable solution to the social issues that road and rail freight transport faces. Sustainability in the context of this research is the ability of a transport system to provide reliable and efficient cargo transport services while minimizing the negative impact on the environment, society, and the economy. This requires balancing economic gains with social responsibility to meet the present transport need without compromising future societal impact.

This allows Inland Waterway Transport to gain significant market share due to its large capacity and low negative societal impact. However, to realize the potential of IWT, several key challenges affecting the competitiveness of IWT must be addressed, which include port congestion, infrastructure limitations, and regulatory barriers. Given this, the current research examines how IWT operations can be improved to attract more cargo volumes (containerized) and increase its modal share.

This introductory chapter is further divided into seven sub-sections. Section 1.2 discusses the background and rationale of the study. Section 1.3 presents the overall objective of the research and the research questions. Section 1.4 presents the research approach, while section 1.5 presents the scope of the research. In section 1.6, the added value of the research is presented, and finally, section 1.7 presents the structure of the thesis.

1.2 Background and rationale

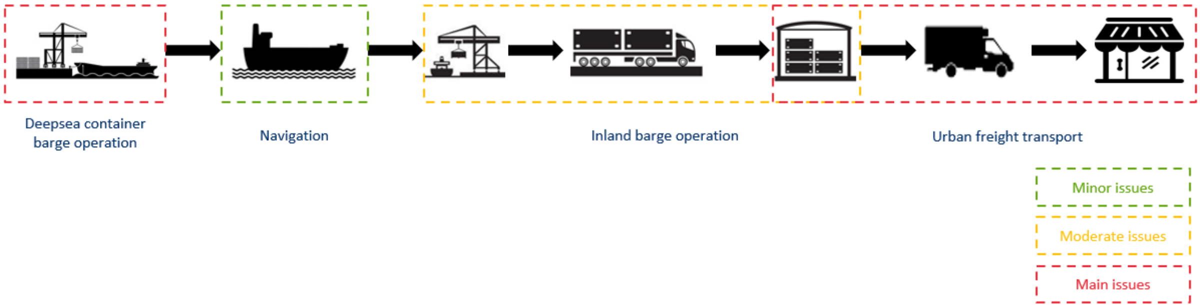
The rationale of this thesis stems from the need to enhance and strengthen the competitiveness of IWT. IWT competitiveness in this research is a multifaceted concept involving a range of factors that affect the ability to transport cargo to shippers efficiently and effectively. This includes the ability of IWT to provide reliable, efficient, and cost-effective transportation services compared to other transport modes (mainly road transport). Thus, enhancing competitiveness is examined in two stages: the IWT port-hinterland container transport (specifically focusing on port barge operations) and the IWT urban freight transport. These two stages differ in terms of distance covered and in their operations.

Container inland waterway hinterland transport focuses on container transport from seaports to inland locations, such as warehouses and distribution centers, with large quantities of goods being transported over long distances. Meanwhile, IWT urban freight transport involves transporting goods via IWT in smaller amounts within cities and urban areas over a short distance.

Despite their differences, these two stages share some similarities in that they both utilize the waterways and can provide a cost-effective alternative mode of transport road transport. Furthermore, they both can be used to complete the transport from the seaport to the final consumer, thereby eliminating, to a large extent, the use of trucks within the whole transport chain.

This research focuses on these two stages because of the major issues they generate in the hinterland supply chain between the seaport and urban areas (Figure 1.1). For instance, there have been persistent congestion issues and poor handling of container barges in seaports. At the same time, urban freight delivery with trucks has been affected by increasing negative externalities and the need for a better alternative with less negative societal impact.

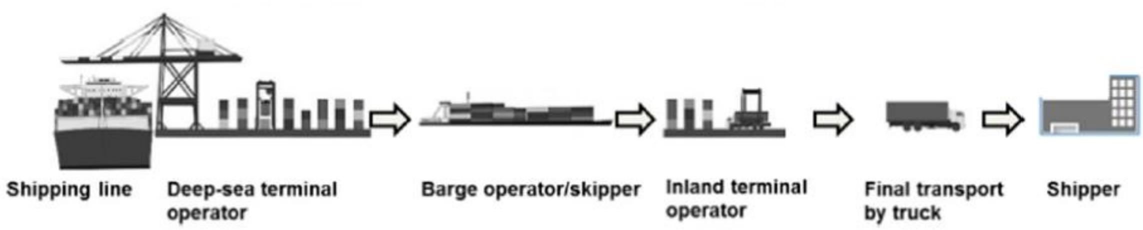
Figure 1.1: Port-urban area supply chain



1.2.1 Stage one: IWT port hinterland container transportation

The first stage focuses on port-hinterland container transport via IWT and the different issues affecting the competitiveness of IWT in this stage. These issues can be linked to the operations and handling of container barges in seaports. The first issue concerns the appointment between shippers and shipping agents about the arrangements of transport conditions and delivery options to and from the port. Generally, barge transportation is cheaper than trucks, enticing shippers with large volumes to use IWT transport services. With this comes high expectations for container barges to be fast, reliable, and timely. Unfortunately, these expectations are challenging for barge transport to meet partly due to the level of coordination and agreement needed from various parties in the transport chain (Figure 1.2).

Figure 1.2: Transport chain of container barging



Source: van der Horst, Kort, Kuipers, & Geerlings, (2019)

The second issue is the inability to pick up and deliver cargo in the shortest time possible. This is due to the high congestion level of container barges in the port, mainly caused by low priority and poor handling of the barges in the sea terminals (van der Horst, 2012). The high congestion and uncertain waiting time disrupt the planning and schedules of the barges, making them unreliable for shippers with a low tolerated risk of stock-out.

Finally, inland barges have small call sizes and have no contractual relationship with deep-sea terminals (Shobayo & van Hassel, 2019). The contractual relationship is typically governed by a transportation agreement outlining the terms and conditions under which the deep-sea terminals provide the containers to the barge operator, who will transport the cargo to the destination. This type of agreement generally includes details such as the volumes of containers to be transported, the timing and frequency of barge services, rates and fees to be paid for terminal handling, any special requirements or responsibilities of each party, and the limitations or exclusions of liability in the event of delay during handling and transportation.

Due to the small volumes per terminal, they must make several calls to different terminals (6-8 calls). But because they have no contractual relationship with the deep-sea terminals, they need to wait for an available berth and crane facilities at each terminal, thereby disrupting their planning, which leads to high barge congestion levels in the seaports (Shobayo & van Hassel 2019). According to the barge performance monitor (2019), waiting time and sailing time between the different terminals contributed to at least 60% of the total time spent in the port.

1.2.2 Stage two: IWT urban freight transportation

The second stage concerns expanding IWT into the urban context for urban freight transport. This is an essential component in the whole supply chain network because this is where the goods are made accessible to the final consumers. Most cargo in this part of the supply chain is characterized by small and frequent volumes transported from the distribution centers to stores and supermarkets within the city and urban areas. The complex delivery system attributed to this type of cargo flow has limited the scope of IWT in gaining market share in urban freight distribution (Behrends, 2012).

The limited scope of IWT and rail transport has made road transport the dominant mode of delivering goods to urban areas. According to De Langhe (2019), using this mode (road transport) for urban freight distribution has resulted in different challenges, the first of which is the issue of congestion. According to Alessandrini et al. (2012), the increasing freight volumes caused by low inventories, timely deliveries, and a growing B2B and B2C relationship have automatically led to an increase in the number of freight vehicles in delivering the goods to the cities, thereby contributing to an increase in road congestion.

The second challenge in this stage is related to pollution. Kopicki (2009) notes that one-fourth of CO_2, one-third of nitrate oxide, and almost half of the other particles emitted by transport activities can be linked to trucks and vans in the city. Dablanc (2007) states that cargo movement within urban areas represents between 20% and 30% of vehicle kilometers. This emits around 50% of pollutants by all transport activities.

The third challenge is the high risk of accidents. European Union (2017) reveals that road freight transport accounts for over 95% of all freight-related transport accidents. Moreover, Maes (2017) notes that urban freight accidents have a significant share of 35% of urban road accidents. Korzhenevych et al. (2014) note that freight transport accounts for almost 14% of the total road transport estimate for external accident costs. With these statistics, it can be concluded that urban road freight transport contributes significantly to accident risks in urban areas.

Finally, there is the risk of reducing the overall quality of life of inhabitants of urban areas. Besides the main external costs (pollution, congestion, and accidents) caused by urban freight transport, other issues emanating from urban distribution by road, such as increased noise and stress levels, thereby contribute to the negative impact on society such as reduced productivity, a high rate of sickness and an increased mortality rate. All these factors make urban areas less desirable for people to live in.

Based on the different issues identified in the two stages, there is an urgent need to rethink how container IWT can be improved in sea terminals and how palletized barges can be developed as an alternative transport mode for urban freight delivery. Quak (2008) noted that the success of transport rests on the balance of four factors: innovation, logistics, stakeholder collaboration, and policies. In this sense, examining the successful implementation of these factors in the container/palletized barges is crucial. In line with this, this thesis will focus on three aspects (innovation, logistics, and stakeholder collaboration) to improve the current status of container IWT.

1.3 Research objective and questions

This dissertation aims to develop a multi-methodological approach for the economic analysis of container IWT competitiveness in port-hinterland transport and urban freight delivery. In doing this, objective criteria are specified based on the earlier identified two stages. The objective criteria include the following:

i. Develop and analyze new approaches to improve the current port-hinterland container IWT logistics.

ii. Examine the economic feasibility of using inland waterways for urban freight transportation.

Based on this, a set of research questions are developed to address the challenges earlier specified in the two stages. The research questions are identified below:

Stage 1: Port-Hinterland transport

RQ1: What are the main challenges of container barge operations in seaports in North-Western Europe?

RQ2: How can these challenges be addressed? This is further broken down into two parts:

- Analysis of container barge handling and congestion in sea terminals.
- Analysis of the mobile terminal concept as a solution for dedicated barge space.

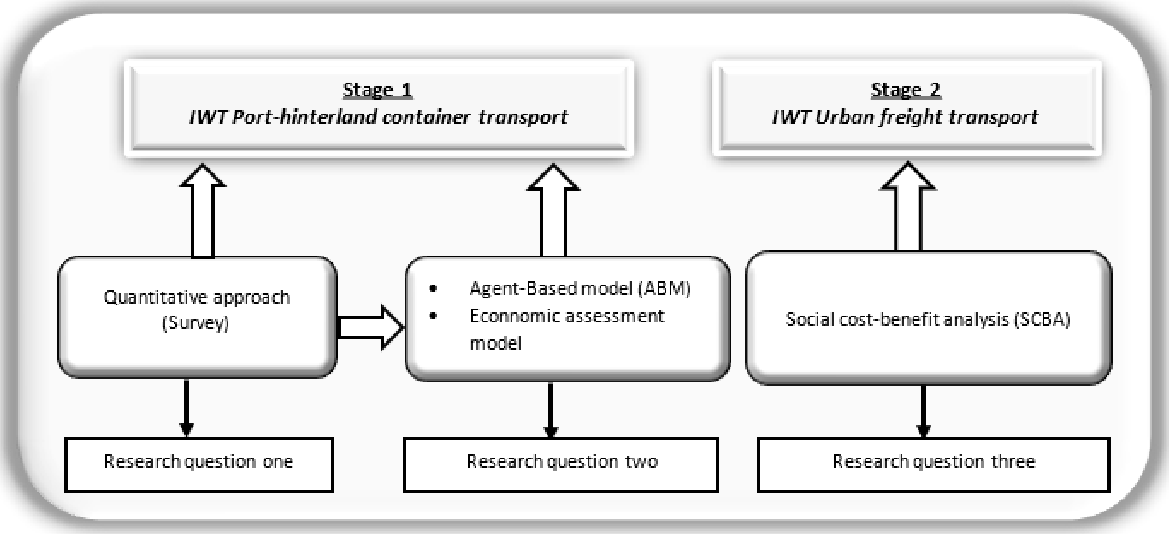
Stage 2: IWT Urban freight transportation

RQ3: Is it possible to deploy (small) inland vessels for urban freight use from a private and welfare viewpoint?

1.4 Research Approach

The dissertation uses a multi-methodological approach to address the specified research questions. This involves multiple methods and analytical techniques indicated in Figure 1.3. From the figure, the first stage is divided into two parts.

Figure 1.3: Research approach



For the first part, a quantitative survey was conducted to determine the practical challenges of container IWT in seaports. This approach provides an objective way to measure the frequency and magnitude of questions and variables. Furthermore, the quantitative survey utilizes closed-ended questions with pre-determined options, which is the case in this research, thus making it easier to code and analyze. This leads to an efficient collection and analysis of data from a large group of the population and a faster method to identify trends and patterns within a sample size.

In addition, the quantitative survey helps to enhance the validity and reliability of a survey result by comparing the survey data across different sample sizes and periods, thereby enhancing the generalization of the survey's findings. Based on this, the quantitative approach is considered the appropriate approach for the survey conducted in this research.

Results from the quantitative survey are then transformed into variables and parameters used to develop an Agent-Based Model (ABM) to answer the first part of the second research question. The ABM approach is considered appropriate in this research as it provides a powerful yet flexible approach to modeling complex systems and dynamics of real-world events in a way that might not be achievable using traditional modeling techniques.

ABM is a simulation technique comprising autonomous decision-making agents with rules, preferences, and behaviors. This modeling framework is often used to understand the complex interactions among individual agents and how each agent makes decisions based on information received from other entities. One key advantage of this model over others is its flexibility to adapt to a wide range of problem domains and capture the interaction in complex systems and variables, which might be difficult to achieve with the traditional mathematical and statistical models. Based on this, the model serves as an appropriate tool to analyze barge congestion issues in seaports, where the priority of barges and deep-sea vessels play a crucial role in determining how sea terminals interact with these two elements known as agents within the model.

The output of the ABM approach is analyzed in detail, and the suggested solution is further appraised using the economic assessment model. This modeling approach is chosen for the second part of the second research question as it provides a robust and objective framework for assessing the costs and benefits of the proposed solution.

The economic assessment model uses a mathematical and statistical approach to analyze the economic feasibility of a solution. By doing this, it considers the economic effect of using a specific solution, accounts for uncertainty and risk in its analysis, provides a basis for comparison with other solutions, and determines under which conditions the solution could be implemented. These factors are particularly important in this research as the aim is to determine the economic implication of the suggested solution for all actors involved and to determine under which condition the solution will be economically feasible.

Regarding the second part (IWT urban freight transport), a social cost-benefit analysis (SCBA) is developed to answer the third research question. This approach is considered appropriate to answer this question as it provides a comprehensive and structured approach that considers all a concept's costs, benefits, and externalities. It involves identifying and quantifying a project's monetary and non-monetary impact and comparing them to determine whether it is economically and socially desirable. As this research aims to enhance the competitiveness of IWT in urban freight, this approach then provides a suitable framework to examine not just the economic feasibility of the small vessel to serve as a good alternative to road transport from both the private and the welfare viewpoint.

1.5 Scope of the research

The focus of this study is on the waterways in North-Western Europe. However, some transferability conditions are highlighted to explain how and under which conditions the results can be generalized to other regions with inland waterway connectivity. As earlier identified, the scope of this study is divided into two stages. For the first stage (container port-hinterland transport), the two largest container seaports in Europe (Antwerp and Rotterdam) are considered. It should be noted here that the Port of Antwerp refers to the Port of Antwerp-Bruges (PoAB). This is due to the recent merger between the two ports (April 2022). However, as most of the analysis in the study had been conducted before, the rest of the study refers to PoAB as the Port of Antwerp (PoA).

These two ports are chosen as they are the largest European container ports with inland waterway connectivity to the hinterland in terms of container throughput (Table 1.1). Furthermore, the Rhine-Alpine corridor was selected as the corridor under study. It relies to a large extent on IWT operations for transporting containers from seaports to the hinterland and accounts for the largest IWT volume in Europe.

Table 1.1: Top 10 busiest ports by container throughput (2021)

Ports	**2021**	**2020**	**2019**	**YOY (%) 2021**	**TEU in 2021 (million)**
Rotterdam	1	1	1	3.2	14.8
Antwerp	2	2	2	-1.91	11.8
Hamburg	3	3	3	8.83	9.25
Piraeus	4	4	4	4	5.65
Valencia	5	5	5	0.36	5.44
Algeciras	6	6	6	0.25	5.12
Bremerhaven	7	7	7	2.31	4.87
Barcelona	8	9	8	12.54	3.32
Gioia Tauro	9	8	12	-1.56	3.14
Le Havre	10	12	9	15.35	2.78

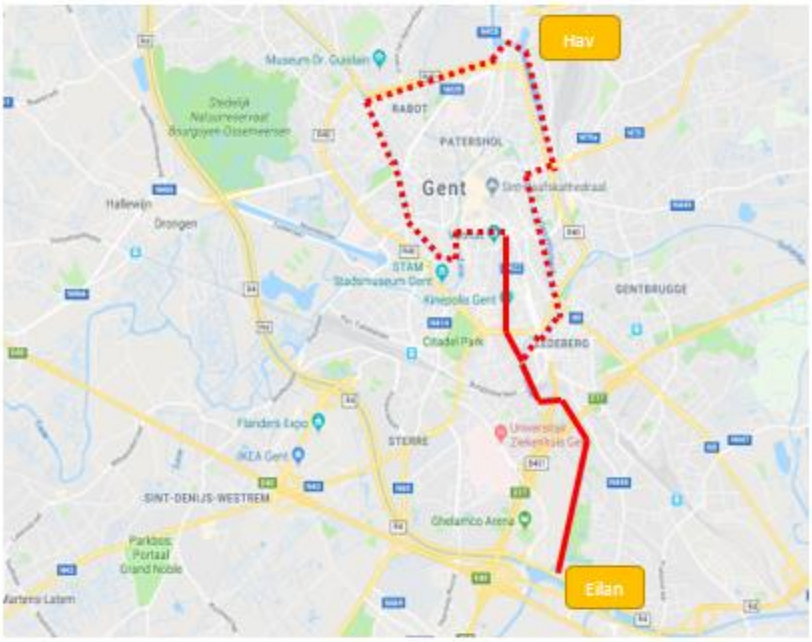
Source: Shiphub (2021)[1]

The second stage (urban freight transportation) focuses on Ghent in Belgium (Figure 1.4). This is because the city is an ancient city with many small waterway connections that connect to the city, thus providing a suitable study area to assess the feasibility of innovative inland vessels for urban freight transport. Also, the study provides the conditions under which the insights from the model and analysis can be transferred to other regions with small water connections.

[1] https://www.shiphub.co/top-container-ports-in-the-eu-2021/

Figure 1.4: Container IWT chain

The Rhine-Alpine corridor, and the detailed Antwerp-Rotterdam route



Test track (solid line) and potential route (solid+dotted)

Source: Own creation based on the NOVIMOVE[2] and Smart waterway[3] projects

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[2] https://novimove.eu/

[3] https://www.imec-int.com/en/research-portfolio/smartwaterway

1.6 Added value of the research

This thesis offers some added value for research in container IWT competitiveness. Firstly, the research provides a comprehensive understanding of the complexities and challenges of container IWT. This is by exploring different research approaches, such as quantitative surveys, data modeling, and data analysis. With this, the thesis ensures more accurate and reliable findings and recommendations for improving container IWT competitiveness.

Secondly, by using multiple approaches, the thesis ensures a cross-validation of results from each method. This helps to increase result confidence and reduces the limitations of the individual approaches to provide an overall robust analysis.

In addition, the thesis helps to address the perspective of different actors in the container IWT. This helps to ensure inclusiveness in the research and ensures the recognition of the needs and preferences of the stakeholders.

Furthermore, by employing a multi-methodological approach, the thesis enhances creativity in research design, which leads to new insights and perspectives that are not apparent through a single method.

Finally, the thesis facilitates interdisciplinary collaboration between transport economics and engineering. This makes the research more holistic and integrated into analyzing how container IWT competitiveness can be enhanced.

In general, this thesis provides some added value to research by comprehensively understanding the container IWT, addressing different perspectives, enhancing innovation within container IWT, facilitating interdisciplinary collaboration between fields, and cross-validating the results of the different approaches.

1.7 Structure of the thesis

This thesis is structured into eight chapters, as depicted in Figure 1.5. Chapter 1 specifies the thesis's motivation, research questions, methodology, and scope. Chapter 2 sets the scene for which the analyses are performed. In doing this, desk research is conducted to review the previous studies and concepts that have been performed on the subject matter.

Chapter 3 focuses on identifying the main challenges of container IWT from the practical perspective. For this, a survey is conducted among the main actors within the container IWT sector (shippers, terminal operators, and barge operators).

Chapter 4 presents the potential solution to challenges related to container barge congestion and handling in sea terminals. For this, a system dynamic agent-based modeling is developed to examine three scenarios and determine the optimum scenario to reduce congestion and enhance barge handling.

Based on the recommendation in Chapter 4, an economic assessment is performed in Chapter 5 to determine the economic feasibility of a dedicated container barge solution for barges in seaports. For this, an assessment methodology is proposed to demonstrate the economic potential of using the Modular Mobile Terminal as a potential solution for floating consolidation and dedicated handling space for container barges. In doing this, time savings optimization and cost estimation models are developed. The proposed methodology combines logistical and economic aspects in a unified framework. It then provides insights into the MMT design, potential time and cost savings, operational constraints, and the market that can be targeted.

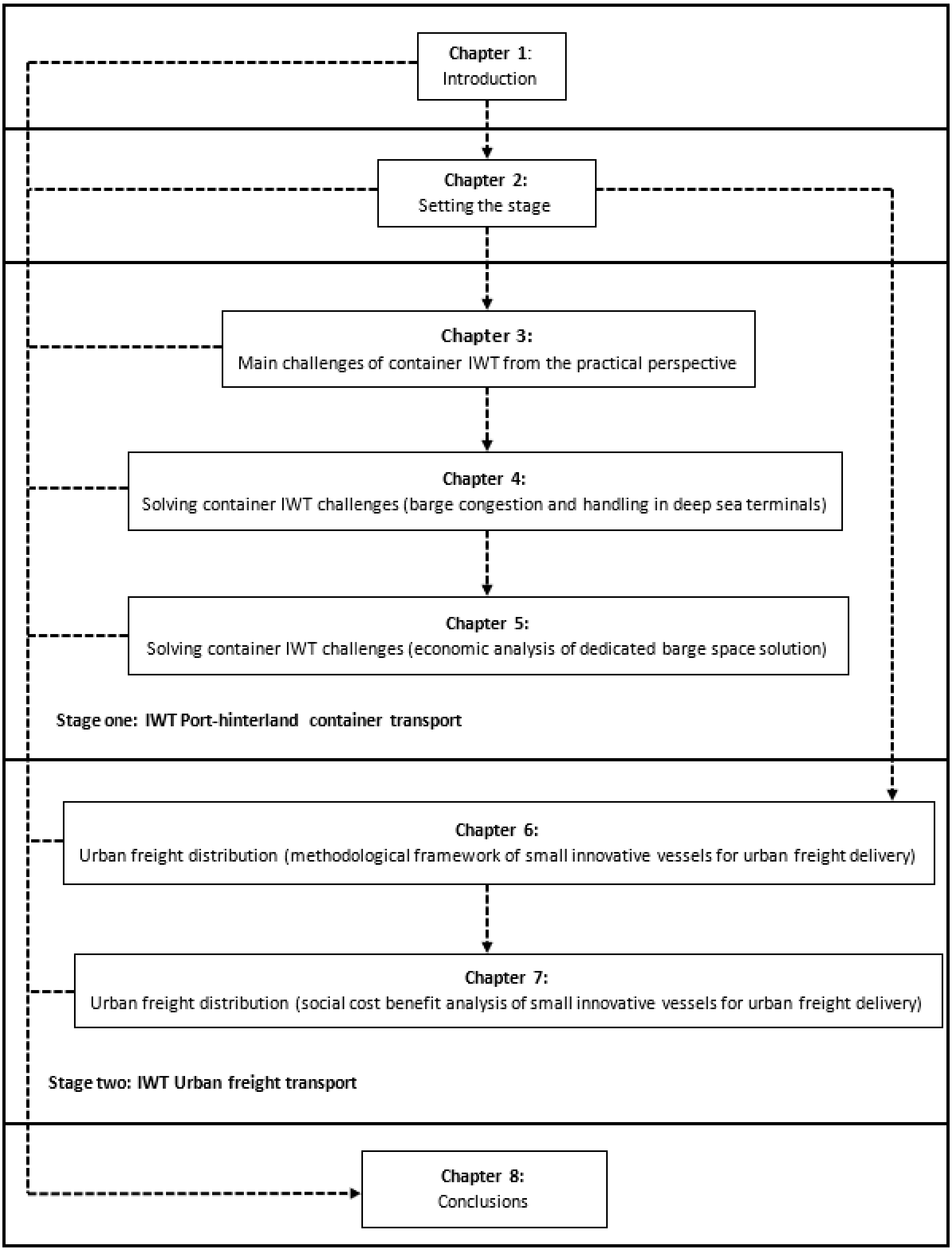
Chapter 6 focuses on the second part of the thesis by developing a methodological framework for assessing the economic feasibility of small innovative vessels for urban freight delivery from both private and welfare viewpoints. In doing this, the chapter identifies and analyzes the main actors, the possible outcomes of the concept for each actor, and their decision criteria. Based on this, the evaluation techniques to examine the project's feasibility for each actor are specified.

In addition, the chapter elaborates on the identified techniques by developing a model that calculates each evaluation technique and examines the decision criteria. In doing this, a cash flow model is developed for vessel owners, a Total Logistics Cost (TLC) model is developed for cargo owners, and an external cost model is developed for society.

Based on the methodological framework developed in Chapter 6, Chapter 7 then applies this framework to a specific case study and analyzes the economic potential of this concept from the private and welfare viewpoint. The chapter examines and compares two transport modes; the proposed concept (small vessels) and the traditional mode (trucks). 16-tonne capacity was considered for the trucks, while four different vessel categories were examined for IWT transport (conventional Pallet Shuttle Barge (PSB), conventional Zulu, autonomous Pallet Shuttle Barge (PSB), and autonomous Zulu). Financial and total logistics cost analyses are performed from the private and welfare viewpoint to determine the concept's impact on the respective actors.

Finally, in Chapter 8, the overall conclusion of the thesis is presented. In doing this, each chapter's main findings and observations are discussed, and comprehensive recommendations are suggested from the scientific, implementation, and policy viewpoints.

Figure 1.5: Structure of the thesis



Chapter 2 - Setting the stage

2.1 Introduction

This chapter presents the desk research conducted for container IWT port-barge operations and IWT urban freight delivery. The desk research was approached by systematically searching academic databases and online libraries. This search was based on some specific keywords, which include:

- Hinterland container IWT transport.
- Demand for container barge transport.
- Challenges of container barge transport in Europe.
- Existing solution for container barge issues in seaports.
- Urban freight transport.
- Urban freight flows.
- Urban freight via IWT.
- Palletized cargo transport via IWT.
- Pallet shuttle barges.
- Automation in IWT.

These key sentences were based on research conducted between 2007 and 2021 for container IWT port-barge operations, while the research on IWT urban freight delivery focused was based on the research between 1996 and 2019. In addition, some working definitions of key terms used in the study are identified and described for clarification. These terms include:

Inland Waterway Transport: refers to transporting containers or palletized cargo using a navigable waterway within a country or region using specialized vessels designated to navigate these waterways.

Shipper: In the context of this research, a shipper is a company or person that owns and transports the cargo from an origin to a destination. Hence, the shipper is responsible for preparing the cargo, looking for the transport service, and paying for the transport services.

Skipper: A skipper, in the context of this thesis, is a person in charge of navigating the inland vessel. The skipper is responsible for the safety of the vessel and the cargo on board and for making decisions about the vessel's speed and course.

Barge operator: A barge operator is defined in this research as a professional in charge of operating container barges. They are responsible for the smooth handling (loading/unloading) of cargo on the barges and ensure that the cargo reaches its destination as when agreed. This person could be the skipper in the case of family-owned independent vessels or someone appointed to monitor the operations of multiple vessels in the case of a shipping company.

Terminal operator: This is a professional or a company responsible for coordinating the movement of containers, managing logistics, and ensuring that all operations within the terminals comply with safety and security regulations within the port area. They also work closely with transportation companies such as trucking companies, shipping lines, and barge operators to ensure that containers are moved efficiently and effectively.

Having described these working definitions, the rest of this chapter is described as follows. Section 2.2 focuses on container hinterland transport via IWT. In section 2.3, IWT urban freight transportation is discussed. Finally, section 2.4 discusses the key findings, the research gaps, and the added values of the proposed methodologies in addressing the research gaps.

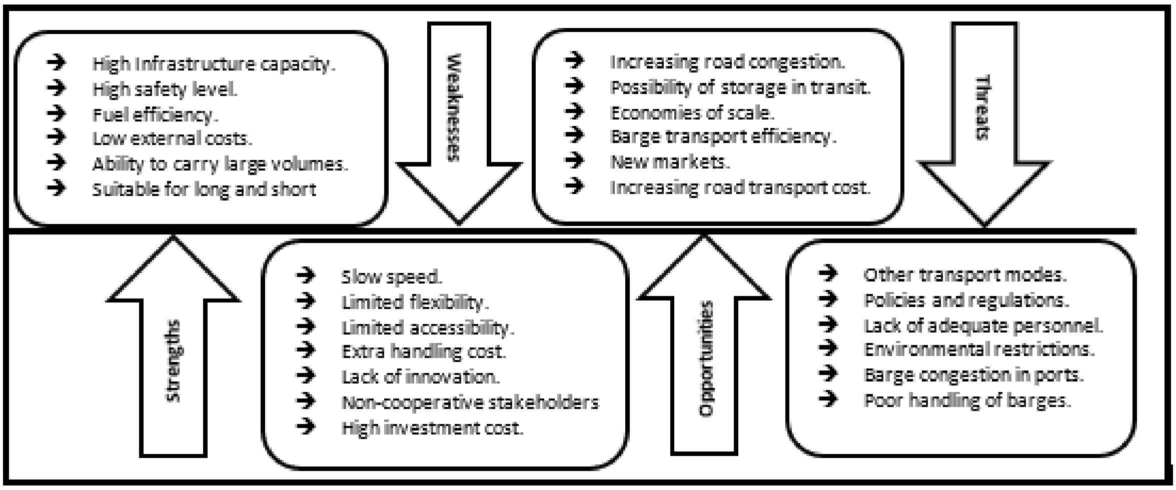
2.2 Hinterland container transport via IWT

The importance of maritime transportation in international trade development over the past years cannot be overemphasized. This has led to massive growth in the world economy and resulted in the movement of high volumes of containers. The increase in container growth has led to the need to develop bigger and more modern ports to keep up with the envisaged growth in container shipping. Within these ports exist different deep-sea terminals that handle large container volumes that are either transhipped or transported to the hinterland. However, these terminals have been pressured to efficiently handle these container volumes (Fan, Wilson, & Dahl, 2012). Enhanced handling of container barging could provide a solution to this and also help improve port performance and hinterland services. This could further enhance the attractiveness of stakeholders and shippers to shift to inland transportation (Konings, Kreutzberger, & Mara, 2013).

Inland waterways flourished in Europe in the late 17th century and into the 19th century. According to Carlen, Josefsson, & Olsson (2013), the waterways network was extensively extended by constructing canals to link with the natural waterways during this period. Hesse (2010) noted that inland waterways were an excellent platform for goods exchange; thus, it was strategically important for cities along waterways and shorelines. This was the trend until the development of rail transportation in the 19th century, which threatened the dominant position of inland waterways as the main mode of freight transport in Europe.

The inland waterway infrastructure network in Europe is 29,500km long, with a large concentration of about 20,000km in the waterway network distributed among four countries (Germany, Belgium, France, and Austria) (Wiegmans, 2005). This creates the potential for these countries to explore the possibility of a modal shift from road transport to IWT. This extensive network has, however, been underutilized as more attention has been focused on road transport. This is partly due to the sector's weaknesses and threats (Figure 2.1).

Figure 2.1: SWOT analysis of IWT



Source: Own creation based on Gort, (2009), Wiegmans, (2005)

Based on this SWOT, examining the factors affecting container barge transport demand is essential. This is explained in the sub-section below.

2.2.1 Demand for container barge transport

The demand for a transport mode is often determined by a set of criteria influencing the shipper's choice. Different studies have been carried out on the selection criteria that influence the choice of a transport mode from a shipper perspective. For instance, Cullinane & Toy (2000) and Bury, Paraskevadakis, Ren, & Saeed, (2017) examined more than 75 studies on the factors influencing the mode choice of shippers. They identified eight main factors from the studies. These are transport price, speed/transit time, reliability, service type, product characteristics, flexibility, distance, and frequency. Furthermore, a review of fifteen studies (Table 2.1) indicates that transport cost, transit time, reliability, and frequency are the most important variables affecting the choice of shippers in selecting a transport mode .

Table 2.1: Factors influencing mode choice

Author	Time	Cost	Service frequency	Service reliability	Responsiveness	Safety	Loss	Flexibility	Accessibility	Door-to-door distance	Shipment size	Value-added of shipment	Company type	Speed	Accuracy	Scheduling	Convenience
Espino, de Dios Ortúzar, & Román, (2007)	✓	✓	✓														
Shinghal & Fowkes, (2002)	✓	✓	✓	✓													
Wynter, (1995)	✓	✓															
Norojono & Young (2003)				✓	✓	✓											
Bergantino & Bolis, (2004)			✓	✓													
Golias & Yannis, (1998)	✓	✓															
Wigan, Rockliffe, Thoresen, & Tsolakis, (2000)	✓			✓													
Beuthe, Bouffioux, & Maeyer, (2003)	✓	✓	✓	✓			✓	✓									
García-Menéndez & Feo-Valero, (2009)	✓	✓							✓	✓	✓	✓	✓				
Bolis & Maggi, (2003)	✓		✓	✓													
Bergantino & Bolis, (2008)			✓	✓													
Beuthe & Bouffioux, (2008)	✓		✓	✓		✓		✓									
Punakivi & Hinkka, (2006)		✓		✓		✓								✓	✓	✓	✓
Brooks & Trifts, (2008)	✓	✓	✓	✓													
Zotti & Danielis, (2004)		✓				✓	✓										

More recently, Stinga & Olteanu (2019) examined choosing a transport mode in a logistic chain. They identified some key factors from this process that influence the choice of a transport mode. These factors include; cost, quality ratio, efficiency, reliability, journey duration, and the organizational aspect of the transport mode.

To further support these studies with more recent data, a survey was conducted among shippers on their preferred mode and the selection criteria when choosing a transport mode (Appendix A). Results from the survey reveal that the shippers prefer IWT due to the large volume of containers that can be transported via this mode. However, irrespective of IWT being the preferred mode, realistically, road transport remains the suitable choice due to some critical variables considered when making transport choices. These variables include reliable service, transit time, and availability in the transport mode when needed (easy accessibility).

Therefore, the potential of IWT is not fully explored due to these critical variables, as they have led to different challenges within the container IWT sector. Based on this, it is essential to understand the main challenges for container IWT. This is examined from two perspectives; the theoretical perspective and the practical perspective. This chapter only focuses on the theoretical perspective, while the practical perspective is discussed in Chapter 3

2.2.2 Challenges of container barging in Europe

Improving IWT activities could serve as a mechanism to improve port performance and hinterland services, thereby increasing its attractiveness to shippers (Konings, Kreutzberger, & Mara, 2013). To achieve this, collaboration and cooperation must be enhanced among stakeholders such as barge operators, terminal operators, sea carriers, shippers, freight forwarders, waterway managers, and the port authorities. However, this is currently not the case within the container IWT sector.

Container barges visiting different deep-sea and inland terminals often call at the various terminals with small volumes. In doing so, they spend more time waiting and sailing among deep-sea terminals than the time they spend loading or unloading the containers. The high waiting and sailing times reduce their weekly departures, disrupting their schedules and plans. As a result of the loss of time, the capacity of inland navigation is not optimized, thereby increasing the transportation time and cost for the barges.

Furthermore, the small call size and sub-optimal use of the IWT capacity create bottlenecks for barge operators facing several coordination challenges for handling the barges. These coordination challenges can be divided into three categories (Table 2.2).

Table 2.2: Coordination problems in container barging

Coordination challenges	Actors involved
Long stay of barges in ports due to several calls and small call sizes per call.	Barge operators, terminal operating companies, and forwarders.
Inadequate terminal and quay planning concerning the sailing schedule of deep-sea vessels and barges	Barge operators, terminal operating companies, terminal operators.
Limited exchange of cargo	Barge operator, forwarder

Source: van der Horst, 2016

The first coordination challenge can be linked to a few containers that must be loaded or unloaded from the barges and too many calls at different sea terminals, leading to long port waiting times. van der Horst (2012) noted that better coordination and planning from barge operators could help reduce the number of calls. The second challenge is the inadequate terminal and quay planning to handle the barges better. According to van der Horst (2012), the average rotation time of a barge could be as high as 22.5 hours, of which 7.5 hours are used to load and unload while the remaining 15 hours are used for sailing and waiting at the terminals to be served.

The first two coordination problems can be partially attributed to the lack of contractual relationships between the terminal operating companies and the barge operators. The barges are only scheduled and handled after the deep-sea vessels have been attended to. There is often a lot of delay with deep-sea vessels; thus, a contractual relationship between the barge operators and terminal operators could grant barges access to the terminal at a specified time. However, it might be the case that the container that needs to be picked up by the barge is still on the delayed deep-sea vessel; therefore, having a contractual relationship alone does not resolve the issue. Hence, data about the container status and the vessel planning option should also be provided, which could help improve coordination challenges.

This is why the Port of Rotterdam introduced the concept of synchromodality. This means that the choice for hinterland transportation is delayed and only selected just before the arrival of the deep-sea vessel. Doing this lets the cargo details be known, and the appropriate hinterland transportation services can be determined. However, the challenge is that the different parties have little interaction and barely share this information.

The third coordination problem can be linked to increasing the load factors of the barges. By exchanging and reconstructing cargoes, larger call sizes can be made, leading to better handling and fewer terminal calls.

2.2.3 Existing solutions to solve container IWT challenges at the Port of Antwerp

Different solutions have been implemented to improve container barge operations and handling in seaports with IWT hinterland connectivity. This section examines some of the solutions implemented in the port of Antwerp. Although this study focuses on solutions explicitly applied to the port of Antwerp, some are also being used in other large seaports with IWT connectivity, albeit known by different names. The port of Antwerp was chosen due to its proximity to the researcher’s location, as it is easy to collect more information on these solutions. The solutions discussed in this research are selected based on specific criteria defined by Oganesian, Sys, Vanelslander, & van Hassel, (2021). These criteria include; accessibility, information level, accuracy, schedule, other transport modes, target group, port planning, and cargo flow bundling (Table 2.3).

Table 2.3: Overview of the different port-barge solutions

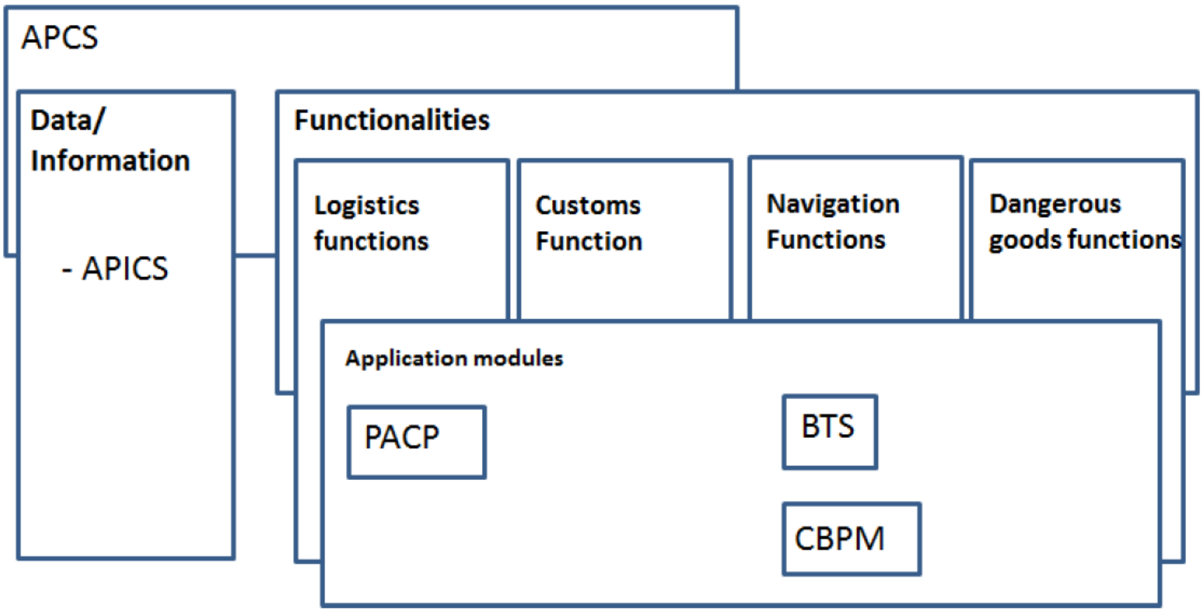
Name of the application		APCS	APICS	AIS	BTS	CBPM	PBS
Type of application		Main platform	Water-bound traffic control (data)	Water-bound traffic monitoring	Barge optimization	Hinterland / bundling	Barge bundling
Open/Closed (everyone can access it)		for registered users	-	+	+	+	
Provides information about:	Port of Antwerp	+	+	+	+	+	+
	Inland terminals	-	+	+		+	+
	Overall	-	+	+	-	+	-
Accuracy		+					+
Time scheduling		+	-	+	+	-	Fixed/ Schedule
Uniting different transport modes	Rail	-	-	-	-	+	+
	Barge	+	+	+	+	+	+
	Truck	+	-	-	-	+	-
	Sea vessels	+	+	+	-	+	-
For whom the application was developed (Target Group)	Port Authority	+	+	+	-	+	+
	Shippers	+		+	+	+	+
	Terminal operator	+		+	+	+	+
	Barge operator	+		+	+	+	+
	Shipping company (carrier)	+		+	+	+	+
	Forwarder	+	-	+	+	+	+
Planning in the port	Locks	+	+				-
	Terminals/ Quays	+	+	+	+		-
	Depots				+	+	+
Cargo flow bundling (accumulation of container volumes provision)		-	-	-	-	+	-

Source: Based on Oganesian, Sys, Vanelslander, & van Hassel (2021)

Antwerp Port Community System (APCS): This is the major platform for electronic data exchange at the port of Antwerp (Figure 2.2). This centralized layer provides information exchange services for the different stakeholders at the port (Carlan, Sys, & Vanelslander, 2016). The system also has the Antwerp Port Information and Control System (APICS), which tends to plan, direct and monitor vessel traffic.

The APICS system can control the barge and vessel planning at the port as it functions in lock planning, cargo declaration, berth reservation, and arrival or departure notification (Port of Antwerp, 2016).

Figure 2.2: Overview of the multilayer digital applications



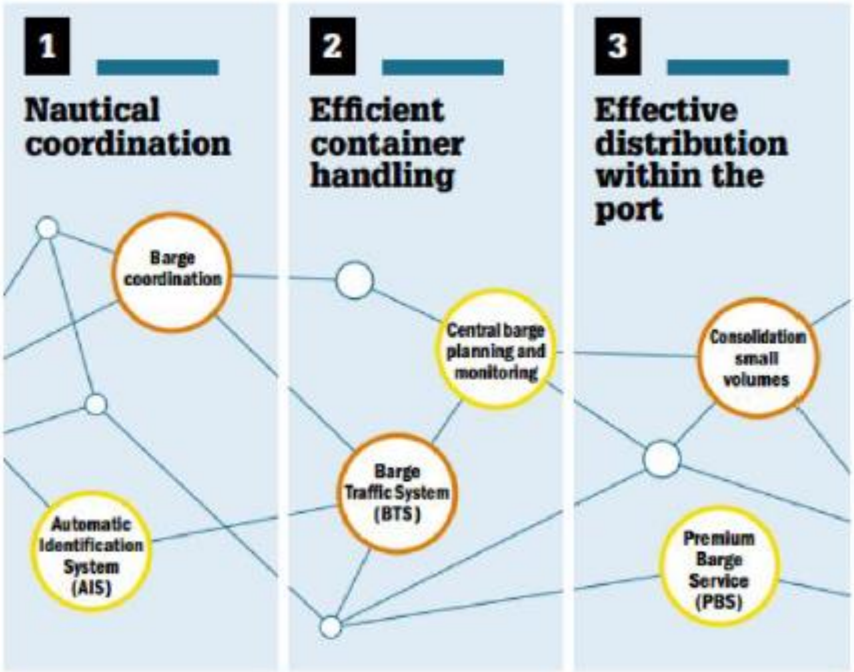
Port of Antwerp (2016)

These two systems (APCS and APICS) are the major systems that have led to the development of other systems explicitly aimed at either barge and deep-sea vessel handling or other activities around the port area. Other systems include the Automatic Identification System (AIS), Barge Coordination System, Barge Traffic System (BTS), Premium Barge Service (PBS), and the Central Booking Platform (CBP).

AIS: This system was implemented to coordinate barge traffic at the port better. This system uses GPS information of barges and deep-sea vessels, such as the vessel's name, speed, position, etc., to transmit information to the terminal. The port mandated this system on all vessels in 2014. The AIS system made it possible for port operators to have an in-depth view of the traffic situation at the port to plan the visit of barges and deep-sea vessels to the locks and terminals (Port of Antwerp, 2017).

BCS: This system is similar to the AIS (Figure 2.3), which integrates barge operators and the port authority and includes the terminal operators and skippers. This is to enhance the route planning, schedule locks, and schedule barges for optimum activities at the port.

Figure 2.3: Barge coordination system

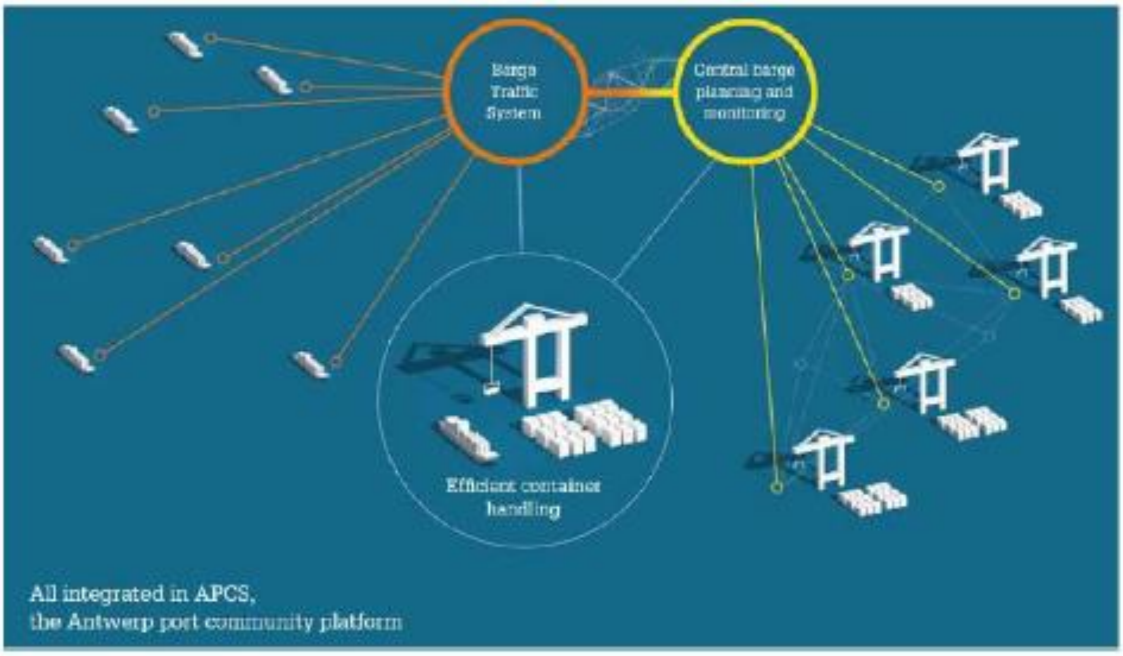


Port of Antwerp Instream Brochure (2017)

BTS: This free web application creates a platform where barges can book a slot and schedule visits to the terminals in a real-time window. The system was developed to optimize the flow of barges around the port. The BTS serves as a communication channel where the barge operator and terminal operator continuously monitor different factors such as the position of the barge, terminal capacity, opening time, sailing schedule, and lock schedule. The system's flow is such that once a barge operator places a request, the terminal operator creates a loading and unloading schedule. The available slots' information is processed and communicated to the barge operator (Port of Antwerp, 2017).

CBPM: This system closely connects with BTS to avoid request conflict and miscommunication (Figure 2.4).The central barge planning and monitoring unit incorporates the various container terminals. This is to improve communication among them to ensure no overlap in the terminal schedule, which helps reduce the turnaround time for barges and enhance barge handling at the port.

Figure 2.4: BTS in connection with the central barge planning and monitoring system



Source: Port of Antwerp - Instream brochure, (2017)

PBS: The PBS was developed to bundle small container volumes to reduce the number of terminal visits by a barge within the port. The PBS works as a barge shuttle service under a fixed daily routine in close connection with consolidating small barge container volumes to optimize resource usage at the port.

Despite all these applications in place, the problems of container barges persist in large seaports. Previous research initiatives have tried to provide different innovative solutions to help improve container barge handling. For instance, Konings (2007) researches the opportunities to enhance container barge handling in the port of Rotterdam. The research proposes improving port barge handling by reorganizing container barges' services. The study identifies three collection and distribution models by which barge services could be reorganized. The first is the container exchange point service model, where all the hinterland vessels call at one terminal, which serves as a container exchange point. The second is the barge service center which assumes that the hinterland vessels have a limited number of seaport terminals to which it places calls and that the terminal choice will depend on the call size. The third model is the multi-hub terminal service model, where hinterland vessels also call directly to large container terminals; however, small container batches are collected and distributed locally.

The findings acknowledge that barges are being handled poorly at the port, negatively affecting barge transportation's efficiency and competitiveness. It was discovered that barge operators would enhance their productivity by reducing the number of terminals they visit at the port. This reduction could be achieved by avoiding terminals with small batches; hence these tiny batches should be reorganized through specialized transport services for collecting and distributing the batches. This would lead to a higher cost; however, the researcher argued that there would be an offset of cost from the revenue generated from avoiding terminals with small batches. This notion can, however, be debated as the distance and organization of the distribution service channel can affect the cost to a great extent. More so, the exchange center point would mean that containers must be handled more often than in the small terminals with few batches, leading to an increase in cost.

Furthermore, Douma, Schutten, & Schuur, (2009) examine the efficient protocol in planning container barge rotations along with terminals in the Rotterdam port to reduce the barges' waiting time. They developed a multi-agent-based control that integrates barge rotation and terminal capacity to understand the system's functionalities. The researchers see barge and terminal operators as opportunists who look to exploit each other without considering how each party would be affected.

The study assumes no disturbances in the operations between the terminal and barge operators; hence, there are reliable appointments, and unexpected delays are not considered. To optimize the alignment between barges and terminals, the researchers propose a decentralized control system to enhance the efficiency of barge handling. This would reduce the line of communication for appointments, which could be automated through the decentralized system, thereby reducing the waiting time. The researchers, however, only consider the simple scenarios and assumptions that do not hold in an actual situation. First is that deep-sea terminals do not only handle container barges. The container barges are given less priority at the terminals due to more priority given to the deep-deep-sea vessels. Furthermore, the terminals have opening and closing periods, implying that they cannot always be opened. Finally, the researcher does not consider disruptions that might occur during operations.

Moreso, Fu, Liu, & Xu (2010) research the rationalization of port resources to enhance handling barge services in Hong Kong. The researchers identify the Hong Kong port's growth area and the barge services issues that might affect this growth. They propose three strategies for improving the barge services at the port: improving port facilities through a centralized control system and consolidating container flows, expanding terminal capacity for barges, and re-opening the river trade terminal for access to ocean vessels. A simulation model was used to analyze the three strategies. They conclude that the centralization strategy offers the best solution to container barge issues in the port. This strategy involves consolidating containers. This would reduce congestion at the port, the dwell time of cargoes, and the waiting time of barges at the port.

In addition, Douma, Schuur, & Schutten (2011) examine the alignment of barge and terminal operations using a service time profile. They try to improve their previous research by addressing the four areas of assumption to make their study more practical and applicable to real-life situations. In this case, they incorporate the restriction of terminals, where terminals can be closed at a specific time of the day. They further include the services of deep-sea vessels in which the terminals handle the barges and the deep-sea vessels, with a higher priority rate given to them. Furthermore, they include a situation where specific containers have specified times at which they must be at the terminal. Finally, they incorporate a situation where the terminals have different capacities and degrees of utilization of services. By combining these new situations, they aim to propose a model to solve the problem of barge handling in a practical scenario to enhance the operations of the barge operators and terminal operators at the port. In doing this, they designed a multi-agent model where they first adapted the base model in their previous study and then incorporated the situation above.

In their findings, it was discovered that opening time restrictions and services to deep-sea vessels significantly affect the barges' visits and the pattern of their arrivals at the terminals. It also found that barges avoid going to the terminals with restricted opening times due to the risk of staying overnight at the terminal. Finally, It revealed that barges determine their rotation based on highly-utilized terminals rather than on low-utilized terminals, which in turn affects the visit of the terminals at the port.

Furthermore, Douma, Schuur, & Jagerman (2011) examine the degree of terminal co-operativeness and the effect on the efficiency of the barge handling process. Their study focuses on how to align the barge operators and the terminal operators in enhancing the barge handling process at the port, using different levels of cooperation among the various players in the handling process, which majorly involve the barge operators and the terminal operators. A multi-agent system is used where the barge and terminal operators are the decision-making actors. This is based on the one hand on the barge operators' aim at minimizing the waiting time of barges at the port, thereby having to decide which order of terminal visit is necessary for the container barge. On the other hand, the terminal operators are looking to make efficient use of the infrastructure and terminal resources; hence they have to decide when to attend to the barges. The model assumes that each actor will exploit opportunities for their benefit with less regard to how the other actor is affected. The study assumes that two barge operators could not rotate simultaneously at the terminal. For the terminal operators, it assumes that they only handle barges without considering deep-sea vessels. It also assumed that the terminals have fixed capacity, are never closed, and only have information on barges already at the port.

It further assumed that all barges have the same objectives, and the same goes for the terminals. There are no disturbances in the operations of barges and terminals, which leads to reliable appointments between the barge and terminal operators since there are no unexpected delays. The study focuses on the degree of responsiveness among terminal operators. For this, they focus on the extent to which a terminal provides insight into its operation for the day, how occupied it is, and the extent to which a terminal is willing to keep up with an appointment. Three scenarios of the degree of responsiveness were considered. The first is focused on full cooperativeness - a situation where a terminal issues the waiting profiles and meets up with the appointment made with barges. The second scenario is part cooperativeness - the terminal gives the waiting profiles but attends to barges on a first-come, first-served basis.

Meanwhile, the third is low cooperativeness - a situation where a terminal does not give insight into the waiting profiles and only attends to barges on a first-come, first-served basis. Results reveal that how terminals deal with barges goes a long way in influencing their performance. Barges will have enhanced performance if there are no appointments but are served on a first-come, first-serve basis.

Additionally, Caris, Macharis, & Janssens (2011) examined container barge transport network analysis through a simulation model. Their research examines how hub scenarios affect the port area's turnaround time and waiting time of inland vessels. The researchers simulate and compare four alternative scenarios. The first scenario develops a hub on the right river bank in the port of Antwerp, where the hub creates a shuttle service to collect and distribute containers to sea terminals. Barges from inland terminals only have to visit the hub to pick up and deliver the cargo. The second scenario is to create a hub on the left river bank, which follows the same services as the first scenario but is just situated on the left bank of the river. The third scenario is the creation of a first multi-hub where a hub is located in the cluster of sea terminals on the left and right riverbank. At the same time, the fourth scenario is the creation of a multi-hub where hubs are also created on both sides of the river bank as in the third scenario, but inland barges only have to visit one hub where they do not have to pass through a lock in the port area. The scenarios were analyzed using the discrete event simulation model. The findings reveal that the fourth scenario leads to a significant turnaround time reduction and the optimal situation for both the terminal and barge operator.

Subsequently, Konings et al. (2013) examined the significant factors to be considered in developing a hub and spoke network to enhance container barge transportation cost performance in the hinterland. The research focuses on improving container barge handling to increase the competitiveness and modal share of barge transportation to the hinterland. The researchers developed a cost model with a comparative analysis of the cost performance of prevailing services to the hinterland by setting up a different hub and spoke networks. A cost-benefit analysis is performed to argue that the hub and spoke network has a net benefit in the entire hinterland chain of the barge transport, provided that the handling costs in the hub are not overstretched.

Furthermore, van der Horst et al. (2019) examine the multidisciplinary analysis behind the coordination problems in container barging in the port of Rotterdam. The research aims to understand the reason for the difficulty in solving the coordination problems of barging and why container barging is still deficient. In this sense, the study adopts a case study approach and focuses on inland barging activities at the port of Rotterdam. The result of the case study approach reveals that even though many interdependent actors have different arrangements on how the container barging problems can be improved, these actors do not provide a sense of urgency on the need to improve the situation. More so, they refuse to cooperate and collaborate towards a lasting solution to the coordination problem, thus weakening the market share and the competitiveness of the container barging sector.

In addition, Al Enezy, van Hassel, Sys, & Vanelslander (2017) developed a cost calculation model for inland navigation. They calculated the specific cost for barge transportation, including waiting time, congestion, externalities, and variable and fixed costs. The researchers develop a generic cost calculation to address the shortcoming of the existing models and applications. Findings reveal that utilizing models for inland navigation should depend on a specific company's input factors due to the differences in ship types, mode of operation, and contract type.

Moreso, Li, Negenborn, & Lodewijks (2017) examine the closed-loop coordination of inland vessel operations in large seaports using hybrid logic-based benders to improve two coordination problems of inland barges in large seaports. These are the extended stay of the inland vessels and inadequate terminal planning concerning the sailing schedules of the inland vessels. They develop a coordination simulation model using logic-based benders and a large neighborhood search. Furthermore, they apply a closed-loop perspective to handle possible disruptions during operations. Results from their simulation reveal three main outputs. Firstly, the port time of inland vessels in the port is reduced using the approach, while the terminal idle time can also be reduced considerably. Secondly, vessel owners can choose how many extra inter-terminal containers to transport to increase their economic benefits. Finally, the system creates flexibility to handle disturbances or accidents that might happen at a terminal. This is done by quickly rotating the vessels so there will be no delay or congestion within the system.

Subsequently, Zheng, Negenborn, & Lodewijks (2017) researched the closed-loop scheduling and control of waterborne AGVs for energy-efficient inter-terminal transport. For this, they simulate the possibility of using waterborne autonomous guided vessels. The waterborne AGVs are controlled in a cooperative, distributed way. The proposed algorithm reveals a positive potential for applying waterborne AGVs for inter-terminal operations. However, this research is limited to the Rotterdam port, as more technological and methodological upgrades must be made to extend the model to other seaports.

Li, Negenborn, & Lodewijks (2017) also examine how to plan inland vessel operations in large seaports using a two-phase approach. They propose a two-phased planning approach to improve the port time and congestion issue of container inland barges at seaports. The first phase focuses on the practical constraints, such as restricted opening times of terminals, the priority of sea-going vessels, and the capacities and sizes of the different terminals. The second phase, meanwhile, considered the possibility of inland vessels carrying out extra inter-terminal transport tasks. Mixed-integer programming (MIP) and constraint programming (CP) were used for these two phases. Results from the simulation indicated a significant improvement in the port time and waiting time of barges at a seaport.

Furthermore, Zweers, Bhulai, & van der Mei (2019) examined the optimization of barge utilization in hinterland container transportation. For this, they examined how the container barge capacity can be optimized to reduce the number of terminal visits and enhance barge handling in seaports. To achieve this, they developed an integer linear program (ILP) and heuristic solution to solve the ILP in two stages. Results revealed that the heuristic solution provides an optimal solution to barge utilization, thereby reducing costs by 20% compared to the base case where no optimization is performed.

Finally, Oganesian, Sys, Vanelslander, & van Hassel (2021) examined the impact of container barging (un)reliability in seaports on shippers. The research aimed to propose a solution for optimizing container barge handling in large seaports. In doing this, the researchers examined the steps taken by actors to improve the situation of barge handling. At the same time, they also examined the transport-economic impact of the unreliability issues of container barging on shippers. A variance analysis was conducted to investigate the reliability issues, and afterward, a total logistical cost was calculated to examine the transport-economic effect on shippers. Results reveal that unreliability is still a significant issue for container barging and can be linked to a lack of contractual relationship between the barge operators and the deep sea terminals. More so, it was revealed in the result that if unreliability and lead time can be reduced, shippers would save a substantial amount in the logistical cost. This implies that unreliability and long lead time significantly negatively affect shippers.

The reviewed studies develop advanced models and algorithms to resolve the identified challenges surrounding container inland barges in large seaports. These issues, however, persist. This is because the core challenge affecting these vessels in seaports has not been addressed: the low priority given to container barges (partially examined in the research of Li et al. (2017)). This affects the barges' coordination and results in a high port time and poor handling of the barges in the terminal. Based on this, this thesis will address the research gap by looking at the possibility of having a dedicated terminal space and examining how this could impact the port time, the coordination, and the handling condition of the barges in seaports.

2.3 IWT urban freight transportation

This part focuses on the possibility of transporting goods to urban areas. In doing this, the concept of urban freight transport is examined. Also, the urban trend and the challenges involved in freight distribution to urban areas are discussed. Finally, the idea of using small barges for urban freight transport is also discussed.

2.3.1 Urban Freight transportation

Logistics deals with the flow of goods and related activities along a supply chain. Transportation, meanwhile, is the activity concerned with moving goods between the point of origin to the destination. In doing this, the transport activity creates time and place utility because it becomes valued at a particular destination within a specific period when the consumer needs it. The term urban transportation has no clear-cut definition. This is because researchers have used the term for various activities or purposes. While some researchers use this term interchangeably with urban logistics and city logistics, others have used urban freight, urban transport, goods transport, and urban distribution in place of urban freight logistics (De Langhe, 2019).

Different definitions exist in the literature for urban freight transportation. For instance, Ogden (1992) defines this as the movement of things within, from, and through urban areas. Diziain, Taniguchi, & Dablanc (2014) define urban freight transport as the process in which the logistics and transport activities of companies in urban areas are optimized with attention to the environment, congestion, and energy consumption within a specific market economy. Alessandrini, Site, Filippi, & Salucci (2012) refer to urban freight transportation as bringing goods to the city center. OECD (2003) defines urban freight transport as delivering all consumer goods in the city and suburban areas and handling reverse logistics of used goods such as clean waste. This definition is supported by Behrends, Lindholm, & Woxenius (2008); however, the researchers exclude the traffic flows within urban areas, such as transport goods that pass through urban areas. Diziain et al. (2014) define urban freight transport as transporting goods from, within, and in urban areas for commercial or public purposes.

Quak (2008) defines this concept as the movement of goods distinct from passenger movement and affected by the associated details of urban traffic and morphology. Ambrosini & Routhier (2004) note that the definition of urban freight transport should not only be limited to the movement of goods in, out, and within urban areas. They should also include the purchasing trips of households, road maintenance, waste collections, and other activities in an urban environment. A further definition is given by MDS Transmodal (2012), which defines urban freight transport as the movement of freight vehicles that are mainly concerned with transporting goods in, out, and within urban areas. From the above definitions, different terminologies exist when transporting goods to the city. However, a common phenomenon in these definitions is that urban transport involves activities channelled towards delivering and picking up goods in the cities or urban areas.

In this sense, the term urban freight transport is adopted in this study due to two main factors. The first factor is that the term freight transport deals with all freight activities that are being carried out in the process of transporting different categories of goods. This means it covers not only the transportation of goods alone but also the logistics aspect, storage, and the added value provided in this activity. A second factor for choosing this term is the word urban, a more recognized term than other terminologies used in literature, such as city, town, and metropolitan.

The definition of urban freight transport in this research is the implantation of activities related to the transportation, logistics, distribution, and value-added services to, from, and within urban areas. In understanding urban freight transport, different dynamics must be understood. Firstly, one must understand why there is a movement of goods. This was identified by Allen & Browne (2008), who state that goods are moved for three main reasons. The first reason is the need to collect regular cargo from the point of origin and deliver them to the point of destination. The second reason is the need to collect and deliver waste and postal letters from one point to another. In contrast, the third reason is service-related trips.

Thus, urban freight transport is the interaction between the demand for goods characterized by economic growth, the flow of goods and land, and the supply of transport characterized by infrastructure, road network, route, vehicle fleet, and vehicle movement. Quak (2008) notes that most urban freight transport problems occur on the supply side, while the key to understanding urban freight transport can be found on the demand side. In understanding the dynamics of urban freight transport, the supply chain aspect of freight transport must be examined. This gives an insight into the difference in the modes of delivery such as single drop round trip, multiple drop round trip, centralized goods supply, decentralized goods supply, full truckload deliveries (FTL), and less than full truckloads delivery (LTL) (Julian Allen & Browne, 2008). In determining the factors that affect the supply side of urban freight transport, two main factors are identified by Taniguchi (2001). These factors are the description that constitutes an urban area and determines the level of urban freight flows. These two factors are further elaborated on in the following subsections.

2.3.1.1 Description of urban area

It is essential to clarify the meaning of urban areas and the characteristics of what constitutes an urban area in general and Flemish contexts. This is covered in this section. There is continuous growth among cities in Europe. Urban areas in Europe serve as an essential hub for exchanging goods, implementing social interactions, and are main contributors to economic development. Different researchers have used different terms to refer to an urban context. This term ranges from the city, metropolitan, region, and urban area. Table 2.4 below gives an overview of the different terms used in the literature.

Table 2.4: Urban terminologies

Authors	City	Region	Urban	Metropolis	Municipal	Community	Sub -center
Ratcliff, (1949)			✓				
Wrigley, (1950)			✓				
Newling, (1969)			✓				
Sukopp & Werner, (1983)			✓				
Krugman, (1993)	✓		✓				
Anas, Arnott, Small, Anas, & Arnott, (1998)			✓				
John Allen, Massey, & Cochrane, (1998)		✓					
Robinson & Mortimer, (2004)			✓				
Tsai, (2005)			✓	✓			
Wu, (2006)			✓			✓	
Dinwoodie, (2006)			✓				
Whitehand, (2007)			✓				
Riguelle, Thomas, & Verhetsel, (2007)	✓		✓				
Scott, (2008)	✓		✓				
Macario & Marques, (2008)	✓		✓				
Roca Cladera, Marmolejo Duarte, & Moix, (2009)			✓				✓
Filippi, Nuzzolo, Comi, & Delle Site, (2010)	✓		✓				
Pflieger & Rozenblat, (2010)	✓		✓				
Hesse, (2010)	✓		✓				
Benjelloun, Gabriel, & Bigras, (2010)	✓						
Dessemontet, Kaufmann, & Jemelin, (2010)				✓	✓		
Coppola & Nuzzolo, (2011)			✓	✓			
Gupta, Kumar, Pathan, & Sharma, (2012)			✓				
Russo & Comi, (2012)	✓		✓				
Anand, Quak, Duin, & Tavasszy, (2012)	✓		✓				
Kikuta, Ito, Tomiyama, & Yamamoto, (2012)	✓		✓				
Bu, Duin, Wiegmans, Luo, & Yin, (2012)	✓		✓				
Trentini & Malhene, (2012)			✓				
Arvidsson & Browne, (2013)			✓				
Nuzzolo & Comi, (2014)			✓				
Nuzzolo & Comi, (2014)	✓						
Omer & Gorçun, (2014)	✓		✓				
Morganti & Gonzalez-feliu, (2015)	✓		✓				
Cleophas, Cottrill, Fabian, & Tierney, (2018)	✓		✓				
Ozturk & Patrick, (2018)	✓		✓				
Boussauw et al., (2018)	✓	✓		✓			
De Langhe, (2019)			✓				
Parr, (1988), (2005), (2007b)	✓	✓		✓			

Source: own composition

A noticeable trend in this table is that 'city' and 'urban' are the most widely used terms in an urban context, and these terms are often used interchangeably by researchers. Hence it is essential to clarify these two terms in the context of an urban area. From the legal framework, Dunn (1993), cited in Maes (2017), defines a city as a legally defined area of a physical geographical zone to the number of residents that can live within the geographical location and the density of the geographical location. Meanwhile, an urban area is more extensive than a city regarding geographical zone. It has a high density to accommodate modern developments such as houses, roads, commercial buildings, railways, and bridges.

A further definition by OECD (2003) defines a city as one or more local administrative units that accommodate at least 50,000 inhabitants. Urban is the combination of the city and its surrounding commuting zones. An urban area can describe the broader region around a city. It is not self-governed and comprises different towns in addition to the city. Scott (2008) defines a city as a dense concentration of human activity. This implies that a city is a geographical area where various human activities are concentrated, such as jobs, residential areas, and shopping centers. As can be seen, there is no clear-cut difference between an urban environment and a city; thus, this research will adopt the term urban area to encompass the term city and urban, which were widely used interchangeably by previous researchers.

An urban area is a geographical area that consists of counties within a labor market. This implies that many resident workers commute in and out of the specified area. Parr (2007a) noted that no general definition exists explaining an urban area's different functional activities. Boussauw et al. (2018) defined an urban area as a continuous compact area with a specified minimum population density of which the majority engage in commercial business activities. De Langhe (2019) argued that using the legal city boundaries to define an urban area gives some restrictions in terms of economic activities. An urban area could be a small area with high concentration of shops, and a large area with low concentration.

Some factors distinguish an area as urban. These factors include population density, geography, trade flows, infrastructure, environmental state, and regulatory framework (J. Allen, Browne, & Cherrett, 2012; Boussauw et al., 2018; Diziain et al., 2014; Macario & Marques, 2008; Parr, 2007a; Tsai, 2005). Before the 19th century, before the advent of rails, urban areas used to be surrounded by small waterways such as rivers and canals. These waterways were primarily used for economic activities and freight movement in and out of the city because of the low freight cost and the exploited economies of scale (Anas et al., 1998). Many urban areas are still located around these waterways; however, the waterways are now mainly used for recreational activities, and freight activities have been shifted more toward road and rail transport.

2.3.1.2 Urban freight flows

According to Allen et al. (2012), freight flows from, to, and within urban areas can be based on different characteristics depending on the origin and destination of the cargo. For instance, most freight transport within urban areas comprises more low-volume freight, while trips out of the urban areas are mainly empty trips with lower load factors. Meanwhile, trips coming into the urban areas mostly have a higher volume of freight than trips within the urban area. This is so because most urban areas are mainly net importers of goods and not net exporters, as urban areas are primarily filled with retail stores and shops that are the last line in the supply chain flow and sell goods to the final consumers.

Nuzzolo & Comi (2014) noted that different categories of goods could be transported to urban areas depending on the conditions, requirements, temperature restrictions, weight type, amount of volume, the kind of supply chain, the catchment area, and the threshold value of the goods. De Langhe (2019) classified these categories into three main types: catchment area, supply chain type, and weight driven versus volume-driven freight (Table 2.5).

De Langhe (2019) distinguishes between primary and secondary activities within an urban area in terms of the catchment area and threshold value. The researcher concludes that urban areas with primary activities are catchment areas that have highly-skilled and specialized economic activities. These areas are larger than the local market areas and are primarily involved in wholesale and industrial activities that do not mainly serve the public and end-users. Secondary activities, meanwhile, are the local market where most retail activities and consumer goods are carried out. These catchment areas are primarily for the public and end-users regularly.

Similarly, Tannier, Foltête, & Girardet (2012) noted that goods could be classified based on their values. For instance, goods with a high threshold or quality are more expensive and have a low volume of freight flow. Subsequently, low-value goods are typically cheaper and have a high volume of freight flow.

The second classification of freight flows by De Langhe (2019) is the supply chain type of goods. There are different supply chains for different kinds of goods with the time sensitivity of the goods. According to Figliozzi (2011), there are three supply chains based on the value and time-sensitivity of goods. The supply chain focused on the low value and low time-sensitivity of goods, the supply chain focused on the low value and high time-sensitivity of goods, and the supply chain focused on the high value and high time-sensitivity of goods. These different supply chains affect the freight flow of goods to urban areas.

In addition to the time sensitivity, the supply chain can be distinguished based on retail activities. De Langhe (2019) differentiated four retail activities; independent retailers, E-commerce, supermarkets, and chain stores. According to the researcher, independent retailers are spread throughout urban areas and often rely on wholesalers to deliver their goods. They usually require small volumes of goods with a high-frequency rate, which makes it challenging to consolidate different types of goods for the different retailers; hence most retailers end up picking their goods with their transport. E-commerce has similar activities; they are spread across different homes in urban areas and are often small volumes of goods in high frequency. However, they have distribution centers, and transportation is being conducted by a logistics company using small vans to deliver mostly small volumes of goods to private homes and offices. Due to the complex nature of the supply chain and last-mile delivery of these two activities, the use of waterway transport for freight deliveries of these retail activities becomes almost impossible.

Meanwhile, supermarkets and chain stores have more centralized distribution centers to deliver last-mile freight. In these retail activities, goods are often bundled and consolidated, leading to a high volume of goods transported. Due to the large volume of goods for these retail activities, exploring waterways for freight delivery for chain stores and supermarkets becomes possible. Another possible usage of small waterways transport in urban areas is the transport of reverse logistics and waste from within the city.

The third classification of freight flow is the distinction between weight-driven and volume-driven freight. Freight distribution to urban areas mostly deals with non-bulk goods. These non-bulk goods can be classified as heavy urban and light freight goods. Urban heavy freight, which is freight-driven flows, includes goods such as industrial supplies, construction materials, building materials, wholesale goods, and recycling supplies. Urban light freight, meanwhile, includes household materials, office supplies, small-scale retail deliveries, and service delivery trips (De Langhe, 2019). Heavy goods vehicles (HGVs)s can transport urban heavy freight goods. HGVs are motor vehicles with a carrying capacity of 3.5 tonnes and above, including chassis, panels, and utilities. Light goods vehicles (LGVs) carry urban light freight goods. These vehicles have a maximum carrying capacity of 3.5 tonnes, including the chassis, panel, and utilities. Meanwhile, small waterway barges can be suitable for the two types of goods depending on the retailers' earlier identified activities.

Table 2.5: Urban freight flow typology

Freight flows	Types	Examples	Urban waterway use
Catchment area	• Primary activities • Secondary activities	• Industrial area, not for end-users. • Local market, retail activities, and consumer goods, Public and end-users.	Possible Possible
Threshold value	• High-value goods. • Medium value goods • Low-value goods	• Construction materials • Pharmaceutical products • Groceries, food.	Possible Depends Depends
Supply chain type – time sensitivity	• Low value, low time sensitivity • Low value, high time sensitivity • High value, high time sensitivity	• Grains, waste • Groceries, food • Pharmaceuticals	Possible Depends Depends
Supply chain type – retail activities	• Independent retailers • E-commerce • Supermarkets • Chain stores	• Groceries, food • Variety of goods • Variety of goods • Variety of goods	Not possible Not possible Possible Possible
Weight-driven vs volume-driven	• Urban heavy freight • Urban light freight	• Construction and building materials, wholesale goods. • Household materials, office supplies, and small-scale retail deliveries.	Possible Depends

Source: Own composition based on (De Langhe, 2019)

Urban freight flows are affected by several trends, such as growing freight transport, growing population, urbanization, and increasing sustainability awareness (United Nations, 2016). As a result, urban freight distribution issues, such as additional vehicle kilometers and progressive measures restricting road transport possibilities, make entering urban areas by road more challenging (European Commission, 2018). This challenge could be partially tackled by innovating how urban freight distribution is carried out.

In line with this, alternative deliveries are being carried out in urban distribution. De Langhe et al. (2019) studied the shift from road to rail and tram in the urban context. Also, Alessandrini et al. (2012);

Arvidsson & Browne (2013); De Langhe (2017); Regué & Bristow (2013) have studied this type of urban freight distribution. Only a few scientific papers have been identified in the literature on using IWT for urban transport (Jochen, Sys, & Vanelslander, 2015; Janjevic & Ndiaye, 2014; Chen, Huang, Zheng, Hopman, & Negenborn, 2020). Hence, examining the use of IWT in an urban context becomes necessary. This is reviewed in the next section.

2.3.2 Urban freight via waterways

The unsustainable issues related to urban freight transport have led to the need to think of efficient and sustainable ways of organizing freight distribution in different urban areas. In recent years, local, regional, and national authorities have stressed the need to rebalance the different transport modes and reduce the increasing pressure on road transport in dealing with the growing demand for freight transport in urban areas. In emphasizing the importance of modal shift, the European Commission in 2011 noted that inland waterways should be integrated into the transport system of countries with navigable waters. In recent years, the increasing importance of waterways in the transport system has led to exciting research examining the potential of small waterways in bringing goods into urban areas.

The use of waterways for urban freight distribution is not a new concept. It is the oldest mode of freight transport and plays a vital role in how most cities are set up. Its position in transporting goods to the urban area was taken over by the development of railway transportation during the industrial revolution and subsequently by road transport due to modernization, globalization, economic development, and fast and increasing demand of people.

The growing amount of freight traffic in urban areas and the conscious effort of people in tackling climate change and sustainability issues have propelled policymakers to seek an alternative mode to road transport. Inland waterway transport has great potential in this perspective because of its environmental benefits and the available infrastructure and capacity, which is currently under-utilized in most urban areas (Carlen et al., 2013). A working definition of inland waterways, which the European Commission has also adopted, is cited in Carlen et al. (2013) as protected waters with a maximum wave height of 2.0 meters.

Different projects have been conducted using small barges for urban freight distribution. The following sub-section examines three cases from different cities where public authorities and private players have taken the initiative to use small barges along the waterways. The cities include Utrecht, Amsterdam, and Paris. The cases are examined below.

2.3.2.1 Utrecht and the Beer boat

Utrecht has characteristics similar to the urban freight case study area being examined in this research (Ghent). They are both medieval cities with narrow streets and many small canals. The city is also one of the biggest urban areas in the Netherlands and serves as an essential network for the Dutch rail and road network. Furthermore, the city has one of the largest inland ports in the Netherlands. In general, around 10% of all internal transport passes through the city at a certain point in time, making the city a vital freight transport hub. Aside from this, the city has a large labor market with many jobs. This generates a high flow of passenger movement from and to the city (Alicia, 2016)

The beer boat project (Figure 2.5) within the city kicked off in 1996 with a diesel boat operating along the canals of the city center. The municipality launched this project due to complaints from the breweries about the difficulty in effectively distributing their beers to their respective clients. This is due to the load restriction imposed on trucks within the city. The city owned the boat, but it was leased to private companies for operations. The boat is being used to transport four different breweries from one wholesaler and serves about 65 bars and restaurants near the rivers within the city center.

Figure 2.5: The beerboat in Utrecht

Source: Alicia, (2016)

To further reduce the external impact, especially regarding emissions, the boat was replaced in 2010 with an electric project. Due to the success of this project in Utrecht, an additional electric vessel was put into service in 2012 to increase the capacity of goods being transported to the city center via IWT. The new vessel transported not only beers but also other types of cargo, such as waste.

2.3.2.2 Amsterdam and the Mokum Mariteam Project

The second case is a project that was implemented in Amsterdam. Amsterdam generates a lot of activities, just like in Ghent, requiring a high demand for freight transport from and to the city. This was initially addressed in ancient times using the numerous canals within the city. However, with the advent of modernization and the rise of road freight transport, canals were abandoned for freight transport. However, due to the various externalities in road transport in the city recently, thoughts were developed to use the canals to divert freight traffic. In doing this, the Mokum Mariteam project was developed. The project aimed at delivering goods in Amsterdam through the canals. This was formed in 2007 by two private companies (Icova and Koninklijke Saan) to distribute their products in the city efficiently. The company used an electric vessel with a carrying capacity of four urban trucks (Figure 2.6). The companies used the boat for two purposes; the first was to distribute different categories of goods to their clients, and secondly, it was used for reverse logistics activities (transport of waste). This way, they could achieve maximum utilization of the transport mode.

Figure 2.6: The Mokum Mariteam Project

Source: Alicia, (2016)

2.3.2.3 Paris and the Vert Chez Vous (Urban freight distributor) Project

The vert chez vous project was implemented in Paris, the capital city of France. Due to its iconic nature and strategic location, the city generates lots of activities and thus requires freight deliveries. However, with road transport creating a lot of externalities, just like the other projects, there was an increasing need to use different transport modes for freight delivery within the city center. The urban freight distributor project (Figure 2.7) was launched in 2012 to deliver goods to the city center via small barges and cargo bikes. The project was initiated by Vert Chez Vous company and operated by Euroots. In implementing this project, the barge sails on the Seine, with regular stops in specified locations along the river where the cargo bikes are then unloaded from the barge and used to complete the transport journey. The cargo bikes have a capacity of 200kg each and are used to deliver parcels with a maximum weight of 30 kilograms to B2B and B2C clients. In doing this, the cargo bikes cover an average distance of 20km within the city and make about 3,000 deliveries per day using about a dozen cargo bikes, usually transported on the barge.

Figure 2.7: Urban freight distribution project

Source: (Alicia, 2016)

A common phenomenon with these projects is that they are all developed out of the need to create a sustainable alternative to the growing urban freight traffic to reduce the increasing negative externalities of road transport. Regarding sustainability, van Lier & Macharis (2014) stated that IWT from an urban perspective could be desirable. This conclusion was reached by calculating the yearly transport cost savings generated from using IWT to pick up goods in place of 255,000 trucks that could have made the same annual trip from the inland port in Brussels. This calculation was conducted for different categories of goods, such as bulk products—building materials, petroleum products, food products, and containers. However, due to the slow mode of this transport option, it requires economies of scale to compete with other transport modes, especially road transport.

Due to its relatively slow speed and possible high lead time, it is suitable mainly for transporting bulk goods and cargoes that are not time-sensitive, such as dry bulk, liquid bulk, and breakbulk. However, since the 1980s, container transport has experienced a significant increase in IWT transport, especially from the main seaports in the Rhine area. Besides bulk and container goods, specific niche cargoes such as cars, trucks, powders, gases, and palletized goods have focused on IWT transport in recent years (Hekkenberg & Liu, 2016). These cargoes, however, do not form a significant portion of the IWT market yet. In light of this, the focus of urban IWT in this study will be on palletized cargoes and consumer goods, though attention will also be given to some industrial goods. Hence, the analysis will be based on three palletized cargo types (high-, middle, and low-value goods).

2.3.3 Transport of palletized cargoes in IWT

Palletized goods are generally transported into the city via trucks and vans depending on the goods' size, weight, and volume. This generates negative externalities such as pollution, congestion, accidents, and noise that affect the daily lives of those living in urban areas and contributes significantly to social, ecological, and economic costs (Mommens, Lestiboudois, & Macharis, 2015). According to the researchers, palletized cargoes contribute about 23% of Belgium's freight units for all freight transport. This results in over a 67million tonnes of yearly palletized goods on Belgian roads in terms of volume. Using IWT for this niche market can lead to significant prospects in reducing congestion and enhancing sustainability. However, according to Mommens, Lebeau, & Macharis (2014), not all palletized goods suit a modal shift to IWT. The researchers identified two categories of goods in previous research that are pioneers of the modal shift to IWT for palletized cargoes. They are the construction sector and fast-moving consumer goods (FMCG).

The first category, the construction sector, is a suitable choice because building materials are already in an operational phase of modal shift to IWT, and more so. After all, palletized transport for building materials with a barge has existed in Paris since the ’80s. The second category is a suitable choice due to the various experiments explained in the previous section. Mommens et al. (2014) researched the economic feasibility of palletized FMCG modal shift to IWT in the Brussels region. This research discovered cost-efficient volumes for palletized drinks in the area. A major challenge with the various identified initiatives is that customers and suppliers are not located near the canals and waterfront. This gives the need for pre-and post-haulages and storage and handling services, which have significantly impacted the economic feasibility of the initiatives and have also become a critical success factor in realizing the modal shift.

2.3.4 Pallet shuttle barge

The Pallet shuttle barge (PSB) is designed to transport goods on pallets or in jumbo bags along small waterways to provide competitive alternative freight transport into urban areas instead of traditional trucks. According to Blueline Logistics (BLL, 2019), This vessel differs from conventional inland navigation vessels and has some characteristics that distinguish it. The main features and differences compared to the traditional inland navigation vessel are depicted in Table 2.6.

Table 2.6: Characteristics of the PSBs

Characteristics	Differences compared to an inland vessel
✓ Automation of pallet routing and handling process. ✓ Barge routing is based on goods flow. ✓ Real-time process control and management. ✓ Combination of waterside hubs with small barges. ✓ Adapted loading and unloading system based on user requirements.	✓ Goods are carried on deck and not in a hold. ✓ Short loading/unloading process. ✓ Lower operational costs due to her small size. ✓ State-of-the-art ship systems. ✓ Single crew and multi-tasking of the crew. ✓ Industrial-scale platform. ✓ No living accommodation on board the barge.

Source: BLL (2019)

So far, Zulu 1 and Zulu 2 (Figure 2.8) are the most active catamaran freight vessels in Belgium and Netherlands, and they shuttle between Antwerp, Brussels, Amsterdam, and Liege. The vessels are 50m long, 2.2m deep, 6.6m wide, deadweight tonnes (DWT) of 323.1 tonnes, and have a carrying capacity of 300 tonnes, equivalent to 198 euro pallets, and a carrying capacity of up to 10 cargo trucks.

Figure 2.8: The Zulu barges

Source: Google photos

Zulu 1 entered service in June 2014, while Zulu 2 was launched in February 2015. The vessels are propelled by a 300 hp diesel engine with rudder propellers and bow-thrusters, making it position itself dynamically. The vessels have simple designs and low repair and maintenance costs. This makes it faster to build and repair. Verberght (2019) noted that the average building period for one PSB is between two and three months. Furthermore, the vessels are equipped with onboard lifting equipment to load and unload pallets, saving time and costs.

PSBs' main targets are small waterways defined by van Hassel (2011) as class II and below according to the European Conference of Ministers of Transport (CEMT) classification established in 1992. This body classified the European waterways into six accounts based on the depth, width, lock size, and bridge of all navigable waterways. The classification is summarized in Table 2.7.

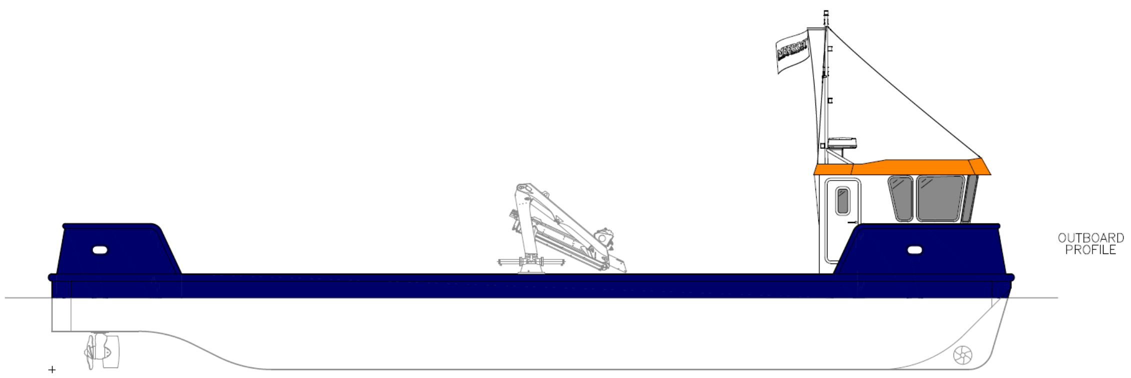
Table 2.7: Classification of inland waterways in Europe

Waterway class (CEMT)	Category	Tonnage	Length (m)	Breadth (m)	Draught (m)	Vessel type
I	Small	250-400	38.5	5.05	1.80-2.20	Spits
II	Small	400-650	50-55	6.00	2.50	Kempenaar
III	Medium	650-1000	67-80	8.20	2.50	Canal du Nord type
						Dortmund-Ems-Canal
IV	Medium	1000-1500	80-85	9.50	2.50	Rhine-Herne-Canal
V	Large	1500-6000	95-185	11.40	2.50-4.50	Large Rhine vessel
VI	Large	3200-18000	95-280	22.80	2.50-4.50	Large container vessel

Source: Verberght (2019)

The PSBs compete mainly with the Spits and Kempenaar vessel types in class I and II waterway. Zulu 1 and 2 mostly fall in category II. However, this study focuses on the city-sized Zulu, which falls under the class I inland waterway category. This type of vessel is a small PSB with a length of 19.5m and a breadth of 5m. It has a carrying capacity of 50 tonnes of palletized goods. A significant advantage of this type of vessel is that it is not subject to any inland shipping legislation due to its length (less than 20m). Thus, it has little to no restrictions regarding navigations and operations, offering the possibility of providing urban freight transport solutions. A conceptual drawing of the vessel is depicted in Figure 2.9

Figure 2.9: Conceptual drawing of a city-sized PSB vessel



Source: Based on the Smart waterway project

Automating some or all of its operations for this vessel type might be interesting to reduce costs and achieve economic feasibility. Hence, it is worth examining the economic feasibility of automated PSBs.

In line with this, the following section briefly explains the concept of automation in vessels, the different levels of automation, and the degree of automation for the vessel type in focus.

2.3.5 Automation in IWT

Inland navigation has been experiencing fundamental innovative automation in recent years. Such is the level of automation that auto-pilot has already been installed in most inland vessels. Also, most vessels' wheelhouse and machine rooms are becoming more automated. A new milestone for the sector to achieve now is implementing a fully automated system (AOS) under different conditions that would only require human intervention in specific situations. According to Verberght (2019), there have been discussions about whether automated vessels would be disruptive or incremental innovations that will gradually replace the crew member. The response to this ongoing discussion lies in the level of automation in the vessels, legal issues, and how safe and efficient the automated system will be. However, at this stage, this innovation can potentially redesign the entire supply chain and possibly impact trip planning, freight capacity, fuel efficiency, and safety.

Vessel automation, especially in inland navigation, is particularly interesting to policymakers and stakeholders who have been rethinking different alternatives to the growing freight traffic. For instance, the waterway manager has been experimenting with varying automation methods in Flanders. The Port of Antwerp has also recently tested a fully automated sounding boat for depth measurement. Different experiments have also been recorded in the Netherlands and Norway, where various organizations have devised different ideas to win the race for the first development of automated vessels. Different definitions have tried to explain the concept of automation and distinguish between ''autonomous'' and ''autonomy''. A working definition of automation in vessels is, however, given by Lloyd's Register (2016), which classified the different levels of autonomy in vessels (Table 2.8).

Table 2.8: Classification table of vessels' autonomy levels

Autonomy level	Description
AL(0) No automation function – Manual	All actions and decisions are performed manually.
AL(1) On-ship decision support	An operator performs all actions on the ship, but decision support can provide options.
AL(2) On and off-ship decision support	Decisions and actions are performed autonomously but with human supervision. Humans and data can override critical decisions available on and off the ship for human intervention.
AL(4) Human on the loop	Actions and decisions are performed autonomously but with human supervision. A human can override critical decisions.
AL(5) High automation	Unsupervised automated operations. The system performs actions and decisions.
AL(6) Full automation	The automated system performs unsupervised automated actions and decisions.

Source: Verberght (2019)

However, a more comprehensive definition of the levels of automation in inland navigation is proposed by CCNR, which proposed the different classification levels for autonomous navigation. This classification corresponds with the levels identified by Lloyd's register with the further addition of the roles of the human operator in the different autonomy levels (Table 2.9).

Table 2.9: Automation levels in IWT

Level	Automation	Roles	Description	Navigation	Monitoring and interaction	Fall-back measures	Remotely controlled
0	No automation	An operator performs most navigation tasks	Full-time operation by the boat master, even when there are warning and intervention systems				NO
1	Steering assistance		Application of autopilot in a specific situation. The operator still performs other aspects of navigation tasks.				
2	Partially automated		Application of AOS for navigation and propulsion. The operator still decides and performs other aspects of navigation tasks.				Subject to a specific context. Could be remotely controlled.
3	Conditional automation	AOS performs all navigation tasks	Continuous application of AOS for all navigation tasks, including collision avoidance. The operator only responds to an intervention request or system failure.				
4	High automation		Continuous application of AOS for all navigation tasks. Takes decisions without the assumption of human intervention				
5	Full automation		Continuous and unconditional application of AOS for all navigation tasks. Takes decisions without human intervention.				

Source: Verberght (2019) based on CCNR (2018)

As seen in Table 2.9, there are six main levels of automation (level 0 to level 5). Level zero to two has little to no automation as the operator or skipper performs most navigation, monitoring, interaction, and fall-back measures. However, the automated operating system takes over the navigation, monitoring, interaction, and fall-back measure from level 3 to level 5. The fall-back measures are assigned to the operator only in level 3 (conditional automation). In this case, when there is a system failure, and the system can no longer navigate independently, it allows the captain takes over the vessel navigation task from a remote shore control center operator to avoid a collision. Conditional automation is currently being developed and researched for the Zulu city-sized PSB. Hence, this research will focus on the economic implication of the conditional automated PSB for all identified stakeholders.

Automation is an ongoing and unavoidable development that fundamentally changed the inland navigation sector. The auto-pilot is already installed in most wheelhouses, and the machine room runs more and more automated. One of the following possible steps is the technology for fully automated operation systems (AOS) under conditions and the possibility for human intervention on-board and on-shore, which is currently being developed. Numerous companies are involved in developing the first automated freight transporting vessel, which is foreseen to be available within a few years in maritime and inland navigation (Seafar, Blue Line Logistics, Rolls-Royce, Wilhelmsen, Kongsberg).

While different projects (MUNIN project[4], AAWA, and Yara Birkeland) have focused on innovation and automation in maritime transport, little literature is available on the economic effect of autonomous vessels for inland navigation. Kretschmann, Burmeister, & Jahn (2017) examine the economic benefit of unmanned autonomous ships, and Verberght & van Hassel (2019) developed a method to evaluate automated and unmanned inland vessels. However, their models were only applied to large automated dry cargo barges sailing on rivers and channels (not in an urban context) and transporting liquid bulk (so no cargoes related to city distribution).

In line with this, examining the economic feasibility of IWT for urban logistics is essential. To address these gaps (related to urban freight transport), a social cost-benefit (SCBA) model is developed to determine the economic feasibility of the PSBs and the welfare effect of the small barges for urban freight delivery. This SCBA model is extensively discussed and analyzed in Chapter 6 and Chapter 7

2.4 Synopsis

This chapter presented the desk research conducted on the two stages that have been identified in which IWT competitiveness can be enhanced. As earlier mentioned, IWT's competitiveness in this research is based on a range of factors that affect the ability to provide efficient and effective transport services to shippers compared to road transport. First is the ability to offer lower transport costs for shippers and simultaneously provide economic benefits for the barge owner/operator. Secondly is the ability to reduce the total transport time of cargo from the point of origin to the destination. This includes reducing the waiting time and congestion of barges in seaports. The third factor is enhancing IWT service reliability by increasing frequency, reducing transit time, and ensuring on-time delivery. Finally, the ability of IWT to remain an attractive option even without the internalization of external

[4] MUNIN project, Maritime Unmanned Navigation through Intelligence in Networks, is co-funded by the EU ran from 2012 until 2016. For more information http://www.unmanned-ship.org

costs ensures that the IWT option is not only viable from the welfare viewpoint but also from the private viewpoint.

Aside from the competitive aspect of IWT, there are also sustainability issues where IWT could also play a role in enhancing the modal shift road and solidifying its competitiveness with other modes. As noted in the introduction chapter, sustainability in the context of this research is based on the ability of a transport service to provide reliable and efficient transport services of cargo while minimizing the negative impact on society. Based on this, the sustainability of IWT is assessed in this research based on some factors such as:

Environmental sustainability aims to minimize environmental impacts such as greenhouse gas emissions, noise pollution, air pollution, climate change, and well-to-tank emissions. This implies that internalizing these costs should make IWT competitive and attractive compared to other modes.

Societal sustainability concerns minimizing the cost of transport to society, such as accidents, congestion, and infrastructural degradation. Internalizing these costs should make IWT a more attractive option to use.

Economic sustainability implies that IWT should be economically viable for all actors by generating sufficient revenue to cover investment and operating costs while still providing cost-effective services.

Innovation sustainability is the ability to develop new long-term practices, innovations, and business models that are self-sustainable and can further contribute to the competitiveness of IWT.

Based on these, the first stage focuses on hinterland container transport via IWT. For this, desk research was conducted on the demand for container barge transport, the challenges of container barging in Europe, and the existing solutions implemented to improve container barge transport in seaports. The research concluded that although comprehensive approaches have been proposed to improve the seaport container barge situation, these approaches have not worked effectively.

To address this gap, the research will analyze container barge congestion and handling issues in sea terminals. After this, an economic assessment will be conducted to examine the economic feasibility of the optimal solution in the first analysis. The first analysis is undertaken with an Agent-Based Modeling (ABM) approach, while the second analysis will be conducted with an economic assessment modeling approach.

The ABM approach is appropriate for this research because it can simulate the behavior and interactions of individual agents, such as deep-sea vessels, container barges, and sea terminals within a system. This type of dynamics cannot be captured using traditional statistical modeling techniques. This adds value to this research as it captures the dynamic of the realistic manner of the agent interactions compared to other modeling techniques.

The first benefit of this model for this research is the ability to identify patterns and trends that might not be visible through other modeling approaches. Secondly, the model ensures a realistic representation of the agents, which helps to capture the heterogeneity of agents within the system and their impact on the system-level outputs. The final benefit is the modeling technique's high flexibility to represent different scenarios and changes within the model.

As mentioned earlier, the economic assessment model is used to analyze the economic feasibility of the optimal solution derived from the first analysis. This approach is deemed appropriate for this study as it considers the economic implication of a concept on all actors involved. Based on this, the modeling approach provides added value to this research by first optimizing the cost of container port-barge logistics operations. This can lead to lower prices for shippers and enhance the competitiveness of container IWT, secondly, by serving as a decision-support tool for investors and decision-makers by providing insights into the net benefits of different logistics scenarios that can be derived by implementing a specific concept. This can help make informed decisions on investment decisions and potential market uptake of the concept.

The second stage of this research is conducted on urban freight transport via IWT. For this, desk research was also conducted that focuses on different definitions of urban freight transport, what constitutes an urban area, an insight into urban freight flows and categorization of the flows, different projects that have used IWT for urban freight transport, specific cargo size of urban freight transport, and the theoretical possibility of automating urban IWT vessels. Findings indicate that although innovative vessels for urban freight delivery are interesting, a detailed economic analysis needs to be conducted to determine the economic potential of this concept both from the private and the welfare viewpoint.

To address this gap, a social cost-benefit analysis (SCBA) is developed that examines the economic potential of IWT urban freight from the private and welfare viewpoints. This approach is applied in this research due to its ability to comprehensively assess the costs and benefits of a specific transport mode. It examines the direct financial costs, benefits, and a specific mode's social and environmental impact. Based on this, the approach provides some added value to this research by first helping to identify and quantify the externalities that might be generated using a specific mode. This ensures that all relevant costs and benefits are considered in the economic analysis.

Secondly, The SCBA approach enables the comparison of IWT with other transport modes regarding their costs and benefits. This allows for informed choices on the most suitable mode in an urban freight scenario. Finally, the approach facilitates stakeholder engagement and dialogue by providing a transparent and objective assessment of costs and benefits associated with a transport mode. This can help develop the consensus and support for policies and investments in the urban IWT sector.

Chapter 3 - Main challenges of container IWT from the practical perspective

3.1 Introduction

This chapter answers this thesis's first main research question: *what are the main challenges of container barge transportation in NW Europe?* To answer this question, a quantitative survey was conducted among key actors in container IWT operations (shippers/forwarders, barge operators, and terminal operators).

Chapter 2 already identified some theoretical challenges facing container IWT in Europe via a literature review perspective. Thus, empirical research becomes necessary to confirm and validate these challenges from a practical perspective.

These two perspectives are quite distinct in academic research. A literature review is a critical evaluation and analysis of existing literature to synthesize information from different sources, identify gaps in knowledge and provide a comprehensive overview of existing research. Based on this, the literature review conducted on container IWT challenges was to synthesize different information on the subject matter and provide a comprehensive overview of the studies conducted.

Empirical research through a quantitative survey, on the other hand, involves collecting data through a survey to answer research questions and validate the studies conducted in the literature. This method involves developing a set of questions, administering the questions to a sample of participants, and then analyzing the responses to draw some conclusions from the survey.

The key difference between a literature review and empirical research with a quantitative survey is that while the former provides a theoretical framework to container IWT challenges, the latter is used to validate this theoretical framework and identify these challenges from a practical viewpoint.

Based on this, the current chapter aims to validate the identified challenges from the previous chapter and understand the practical challenges facing container IWT from the practical perspective. To do this, surveys were sent in the form of questionnaires to three different actors (terminal operators, barge operators, and shippers) in five European countries (Belgium, The Netherlands, Germany, Switzerland, and Norway). The questions asked differed per actor and are identified in Table 3.1.

Table 3.1: Survey questions

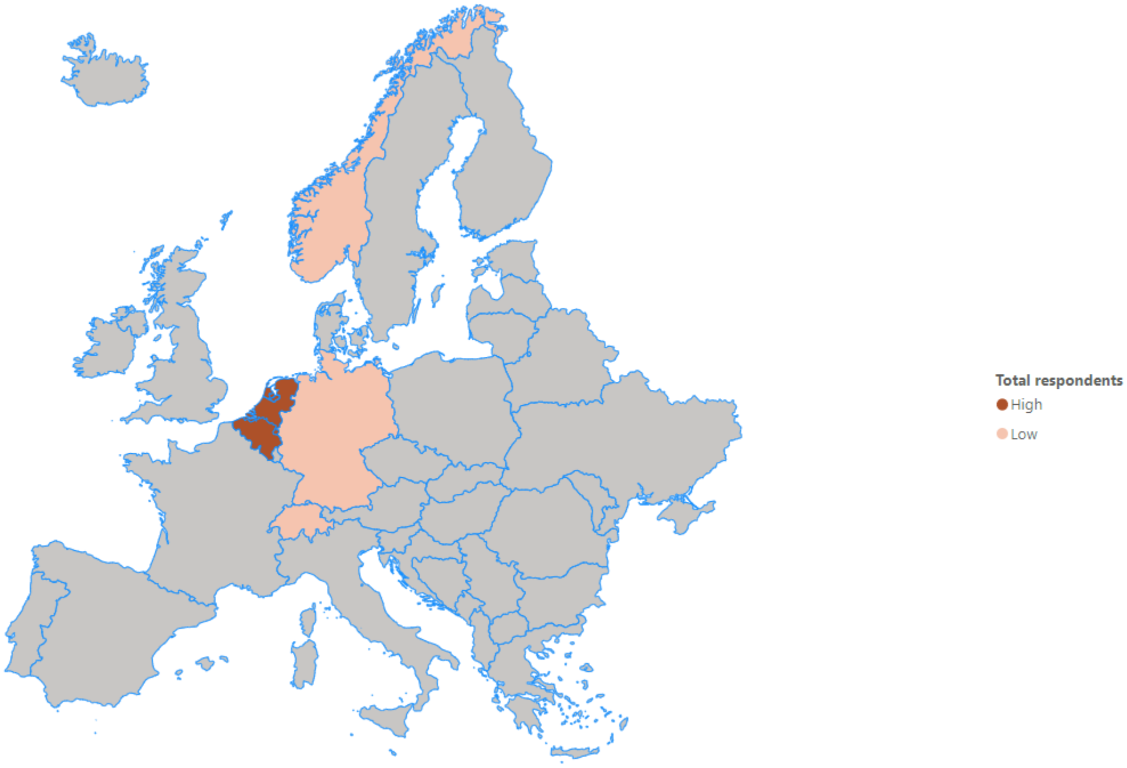
Terminal operator questions
How fast do container freight level and terminal operations recover from market disruptions such as COVID, recession, etc.?
Do you expect an increase in the current container volumes being handled at the terminals in the future?
What are the factors that might contribute to this growth?
Do you expect to see an increase/decline in the modal share of container IWT in the future?
What are the factors that might contribute to this increase/decline?
In your opinion, how resilient are container terminal operations?
What are the factors that would make container terminal operations more resilient?

Who, in your opinion, determines the sailing schedules of deep-sea container vessels and container barges?
Who, in your opinion, plans and sets the ETD and ETA of deep-sea container vessels and container barges for the terminal visit?
Who decides on the planning and organization of container barge operations?
How well do you prioritize the handling of container barges at your terminal?
What do you find to be the current challenges facing container barge handling in terminals?
Would you consider prioritizing handling container barges if they have higher load sizes?
Would you consider prioritizing handling container barges if their schedules are better planned?
Would you consider prioritizing handling container barges if they are better coordinated?
Would you consider prioritizing the handling of container barges if they have dedicated handling terminal space?
Would you consider prioritizing handling container barges if they are more flexible?
Would you consider prioritizing handling container barges if they are more efficient?
What other factors would make you consider prioritizing the handling of container barges?
Barge operator questions
Who, in your opinion, are the major players in inland container barge operations?
Do these players share information among themselves?
If yes, what type of information is shared?
Who decides on the planning and organization of container barge operations?
How flexible are container barge operations? For instance, can planning be easily changed based on new information?
In your opinion, what do you find to be the current challenges facing container barge operations?
To what extent will these innovations make IWT more attractive for container transport? Innovation related to better barge handling. Innovation related to reducing congestion in ports. Innovation related to safe navigation. Innovation related to water levels. Innovation related to new resilient vessel designs. Innovation related to increasing load capacity. Innovation related to better data and information-sharing platforms. Innovation related to dedicated barge terminal space.
How resilient are container barge operations?
What are the factors that could make container barge operations more resilient?
Shipper questions
What is your preferred mode of container freight transport?
What factors are important to you when making modal choices?
Is IWT your first choice when making transport decisions?
If yes/no, why/why not?
How important are the following factors when making transport option decisions? Transport time of the mode. Reliable service in the transport mode. Flexibility in the transport mode. Availability of the transport mode. The technological level of the transport mode. Sensitivity of the cargo being transported. Environmental impact of the transport mode. Frequency of service of the transport mode. Resicilence of the transport mode.
Would you consider using more of IWT if it is more reliable?
Would you consider using more IWT if it has a shorter lead time?
Would you consider using more of IWT if it is more flexible?

Would you consider using more of IWT if it has a higher frequency of service?
Would you consider using more IWT if there is more innovation and technological improvement in the mode?
In your opinion, what other new or improved capabilities would make you consider more use of IWT for container freight transport

The majority of the questions were closed-ended questions. This means that the questions have specific, pre-determined responses and are designed to collect responses in a structured manner. However, the respondents were still given some room to provide detailed open-ended responses if their answers were not in the options provided or if they would like to give further details on one or more of the selected options in the list of answers provided. Responses were collected from the five countries earlier specified, with Belgium and Netherlands having a high response rate (Figure 3.1)

Figure 3.1: Respondents' location analysis



The response rate of these actors is represented in Table 3.2 below, where the shippers/forwarders have a high completion rate (i.e., the response successfully answered all the questions asked in the survey) at 50%. In comparison, the completion rate of barge operators and terminal operators are 33% and 18%, respectively. Although, there are no comparative studies to compare how high these completion rates are compared to similar surveys.

However, the sample size used in this study is relatively small compared to the total population of actors (shippers, barge operators, and terminal operators) represented in the container IWT sector in the Rhine-Alpine corridor. The low sample size is due to the unresponsiveness of most actors when the survey was sent to the different actors. Regardless, the survey represents a first step to identifying the main challenges of container IWT, as this is the first survey conducted to identify the challenges to the best of our knowledge.

Table 3.2: Response rate of respondents

Actor	Total respondents	Completed survey	Completion rate
Shippers/forwarders	6	3	50%
Barge operators	24	8	33%
Terminal operators	22	4	18%

Based on this, the respondents' responses are elaborated on and discussed below.

3.2 Discussion of survey results

This sub-section summarizes the survey results conducted among the identified container IWT actors. As mentioned earlier, the purpose of the survey was to understand the practical challenges facing container IWT from the perspectives of each actor. The survey analysis can be found in Appendix A, Appendix B, and Appendix C.

Starting with the shippers/forwarders, questions were asked to ascertain their perspective regarding the transport mode, the challenges they face with IWT, and the factors that influence their transport choice. Results from the survey reveal that their preferred mode of container transport is IWT. The reason for this is that many of the participants transport large volumes of containers over long distances. Considering the low transport cost/TEU of IWT transport, it becomes a preferred transportation choice for shippers with large volumes transporting over a long distance.

The respondents further revealed that they consider transport cost, reliable service, transit time, and availability in the transport mode to be essential elements when they make transport decisions. With these critical variables in place, only half of the participants make IWT their first choice of transport mode when making transport decisions, even though it is their preferred mode. Making container IWT their first choice of transport mode is due to the low cost per TEU associated with the mode and how environmentally friendly it is. The other half chooses different modes over IWT, citing the unreliability, lack of transparency, and lack of coordination in the sector.

The survey reveals that the barge operators' major stakeholders in container barge operations include the barge owners, barge operators, waterway managers, and shippers. Surprisingly, participants do not consider terminal operators as crucial actors within the sector. Furthermore, most participants (63%) agree that these actors do not share information. According to them, this is due to the actor’s self-centered mentality and only caring about the benefits and gains. Not sharing information has become a significant problem in the IWT container sector. For participants who agreed that the actors share information, a further question was asked to know the type of shared knowledge. They noted that only the necessary data related to the supply and demand of IWT and free capacities are shared and that sharing this information depends on the level of relationship between the parties.

Some measures could be taken to resolve the lack of information sharing issue. These measures include developing a standardized data-sharing protocol that ensures stakeholders share the same information in a standardized and consistent format. This could help improve communication and collaboration among the stakeholders.

The second measure involves developing and encouraging collaborative stakeholder efforts through workshops and seminars. The third measure is implementing a data management system that ensures the collected information is stored and shared efficiently and securely. Another measure is enhancing information transparency by ensuring that information is made available to all stakeholders in a timely, accessible manner. Finally, there is the need to engage a neutral third party, such as a regulatory body or an industry association, to act as a mediator to facilitate information sharing among stakeholders and ensure that the concerns of stakeholders are heard and addressed.

These measures are shared responsibilities of all actors involved in the container IWT, such as shippers, barge operators, terminal operators, and ports. At the same time, a neutral third party could be appointed to facilitate communication and collaboration among the stakeholders.

Concerning the planning and organization of container barge operations, 75% of the respondents identified the skippers/barge operators as the one who decides on the planning and organization of container barge operations. Additionally, a question related to the flexibility of barge operations was asked, and the results reveal that about 50% of the respondents think that container barge operations are highly flexible. In comparison, 25% believe that container barge operations are moderately flexible. Meanwhile, 13% of the respondents perceive that barge operations are slightly flexible. Surprisingly, none of the respondents thinks that barge operations are not flexible.

Responding to the current challenges facing container barge operations, most respondents find poor planning, inefficient barge handling, lack of flexibility, and low water levels to be the main problems confronting container barge transport. Furthermore, other respondents identified other issues outside the list of options provided. The first is that the sector is not as rewarding as it should be compared to its intensive work (i.e., the low risk-reward ratio). An example is the difficulty in rewarding personnel, the equivalent of the hard physical labor put into their shift. This makes it challenging to invest further in new technologies within the sector. The second opinion is that too many container ships are currently sailing. This hurts the freight price as the transport supply exceeds the demand. Thirdly, according to the respondents, too many intermediaries exist in container IWT who all want a share of IWT's financial benefit. The respondents noted that many intermediaries could be removed from the chain, making the sector more profitable for shippers, transshipment companies, and transporters.

In response to innovation in container IWT, many respondents think that innovation related to better barge handling and reduced congestion in ports would go a long way in making barge transport more attractive for container transport. Finally, half of the respondents believe container barge operations are highly resilient. However, the other half believes five action points must be implemented to make container barge operations more resilient and efficient. The first among them is better coordination among barge operators. The second is to improve the current water level threat to the sector. Thirdly, fixed slots for container barges should be allowed in ports. The fourth action point is conducting more personnel training and making the industry more attractive for new and young personnel.

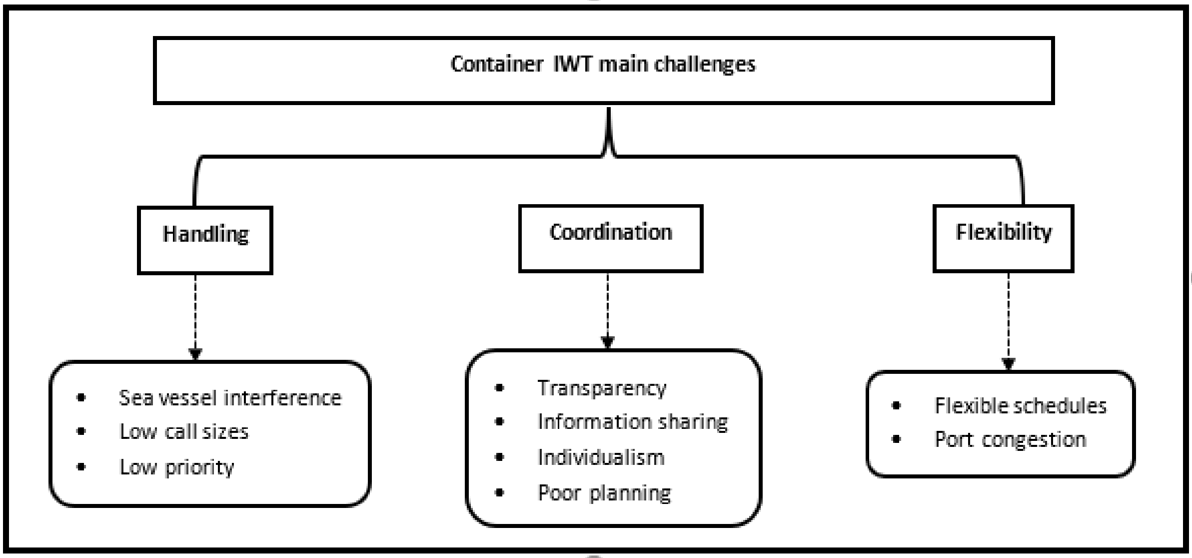
Results for terminal operators reveal that terminal operations and container freight volume usually have a slightly fast recovery from market disruptions, such as recession, COVID, etc. Based on this, the respondents expect an increase in container volumes currently being handled at the terminals, especially in the inland terminals. Seven main factors were identified for the potential volume rise for container IWT. The first factor is the environmental consciousness companies have adopted recently, as more companies are going for the “green way.” The second factor is the growing concern about the increasing congestion level in road transport, forcing companies to transfer their cargo to IWT transport. Thirdly the growing recognition of the potential and benefits of inland container barging. The fourth factor is the bridge level that is being raised, thereby allowing for more containers to be loaded per vessel. The fifth factor is the preference of clients with higher volumes to use IWT and inland terminals to reduce port detention charges. The sixth reason is the evolving global trade, especially the scale increase in the Asia-Europe trade route. However, this scale increase could be threatened due to the growing political tension among countries, the Silk Road initiative, and new rail connections to the far east that might shift some containers to rail. Finally, consolidation and integration among global hubs, shipping alliances, and hinterland networks will help increase the current container volumes.

Most respondents (80%) believe they expect to see an increase in the mode share of container IWT in the future. The main factors contributing to this increase include modal split and greening policies, demand for greener and sustainable transport, nearshoring, the changing logistics pattern, and digital transformation and IT innovations within the sector.

Only half of the respondents believe that terminal container operations are very resilient. Others believe that the operations are moderately or slightly resilient. The respondents identify five factors that should be considered to make the processes more resilient. Firstly, the port should have better, quicker, and more trustworthy handling. Secondly, the port should have more terminal resource capacity for smaller barges. Thirdly, the impact of seagoing vessel operations and other disruptions (such as holidays) should be reduced. Fourthly, more deep-sea terminals should consider the night opening concept to handle the container barges more quicker. Finally, container barging schedules should be flexible to allow for last-minute changes in the number of containers per quay. Finally, most respondents agree that the lack of dedicated barge space in terminals has become a significant challenge for barge handling. This is followed by poor planning and coordination of barge operations, inefficient barge handling, and small call sizes of the barges to the different terminals.

The survey answers the first research question in this thesis, which is to understand the main challenges of container barge transportation. Based on the study, the main challenges of container barge transportation can be divided into three themes: barge handling, coordination, and flexibility (Figure 3.2). Based on this, the survey further confirms the findings from the literature on the need to improve container barge handling, enhance the coordination of container barge transport among the different stakeholders and improve the flexibility of container barge transport.

Figure 3.2: Challenges of container barge transportation

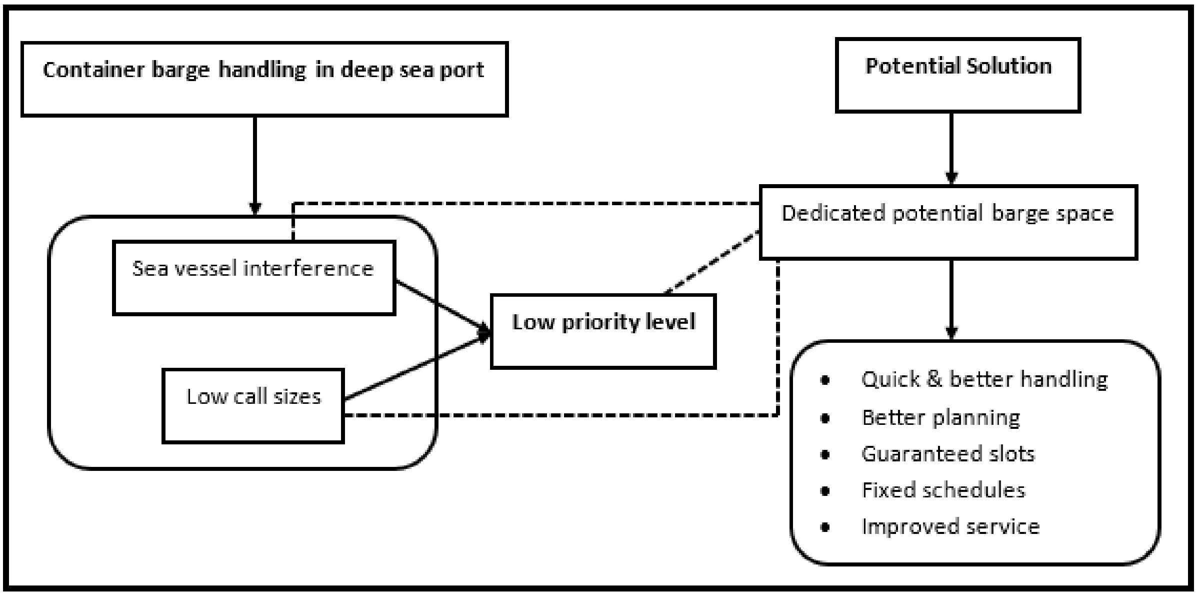


3.3 Synopsis

This chapter focuses on the main challenges of container IWT from a practical perspective. A survey was conducted among the active actors within the container IWT sector to identify the main challenges. The survey result suggests that the main challenges can be categorized into three main areas; handling, coordination, and flexibility. These three areas are further broken down into specific problems. These include the interference of deep-sea vessels, lack of dedicated barge spaces, small call sizes, poor planning, fixed slots, flexible schedules, and low service levels due to port congestion. While some of these problems are interrelated, for instance, dedicated barge space and deep-sea vessel interference (for example, creating a dedicated barge space would eliminate the issue of poor handling in sea terminals), others exist in isolation, such as individualism and personnel training.

Furthermore, while some problems could be addressed by innovation (issues related to handling and flexibility) within the container IWT sector, others can only be addressed through a change in mentality (issues related to coordination) within the industry. Based on this, this thesis focuses on problems that can be addressed via innovation within the sector. Specifically, the thesis focuses on the sub-problems related to barge handling in sea terminals, small call sizes, dedicated barge space, planning, and barge slots/scheduling. The interaction that exists in these challenges is described in Figure 3.3.

Figure 3.3: Mult-level interactions in container barge challenges



Based on the figure, this thesis will examine the barge handling problem in sea terminals and whether this issue can be resolved with dedicated barge space, hence the interaction between dedicated barge space and deep-sea vessel interference. This research is conducted in Chapter 4. Furthermore, there is the issue of small call sizes and whether having a dedicated barge handling space as a container consolidation point could solve this problem. The effect of having the dedicated barge space on barge scheduling, terminal slot, planning, and handling is examined. This research is conducted in Chapter 5.

Chapter 4 - Solving container IWT challenges for barge congestion and handling in sea terminals

4.1 Introduction

This chapter focuses on answering the first part (analysis of container barge handling in sea terminals) of research question two (how can these challenges be addressed). This is done by analyzing barge handling problems in sea terminals and examining whether this could be resolved with dedicated barge handling space.[5]

Researchers have proposed different models on how container barge handling can be improved at deep-sea terminals and how barge congestion issues can be addressed in seaports (Table 4.1 summarizes the different studies). Furthermore, different applications and systems have also been developed to handle barges better and reduce barge congestion and waiting time at the different terminals (Chapter 2).

[5] This chapter is originally published as Shobayo, P., & van Hassel, E. (2019). Container barge congestion and handling in large seaports: a theoretical agent-based modeling approach. *Journal of Shipping and Trade*, *4*(1). https://doi.org/10.1186/s41072-019-0044-7.

Table 4.1: Summary of empirical review on container barge congestion and handling

Title	Author/year	Objective	Methodology	Findings
Opportunities to improve container barge handling in the port of Rotterdam	Konings (2007)	Improving barge handling in the port through reorganizing the services of container barges.	A container exchange point service model, Barge service centre; and the multi-hub terminal service model.	The findings acknowledge that barges are being handled poorly at the port, negatively affecting barge transportation efficiency and competitiveness. Barge operators would enhance their productivity by reducing the number of terminals they visit at the port. This reduction could be achieved by avoiding terminals with small batches.
Efficient protocol in planning container barge rotations along terminals in the port of Rotterdam.	Douma, Schutten and Schuur (2009)	To align barges and terminals so that the barges leave the port according to their sailing schedule and utilize their capacity to the optimum.	A multi-agent-based control that integrates barge rotation and terminal capacity.	Using a centralized system to coordinate the activities at the port will not bring about an optimum solution for both parties. They propose a decentralized control system to enhance the efficient handling of barge handling.
Rationalization of port resources to enhance better handling of barge services in Hong Kong	Fu, Liu and Xu (2010)	To identify the best strategy appropriate for enhancing barge services in Hong Kong.	A simulation model to test three strategies. 1. Improve port facilities through a centralized control system and consolidating container flows. 2. Expansion of terminal capacity for barges 3. Re-opening the river trade terminal to access ocean vessels.	The amount of control that the ship owners are willing to give the independent managers is lower than what looks like a simple declaration of the use of ship management. The ship owners do not usually provide the third parties full management of their vessels.
Alignment of barge and terminal operations using a service time profile	Douma, Schuur and Schutten (2011)	Proposed a model to solve the problem of barge handling in a practical scenario.	A multi-agent model.	Opening time restrictions and services to sea-going vessels significantly affect the barges' visits and the pattern of their arrivals at the terminals. Also, barges avoid going to terminals with restricted opening times towards the end of the day because of the risk of staying overnight at the terminal.

The degree of terminal cooperativeness on the efficiency of the barge handling process.	Douma, Schuur and Jagerman (2011)	Align the barge and terminal operators to enhance the barge handling process at the port, using different levels of cooperation among the different players in the handling process.	A multi-agent system with barge and terminal operators as the decision-making actors.	How terminals deal with barges goes a long way in influencing their performance. Hence, barges will perform better when they do not book any appointment with the terminals but are served on a first-come, first-serve basis.
Network analysis of container barge transport through a simulation model.	Caris, Macharis and Janssens (2011)	To examine how hub scenarios affect the inland vessels' turnaround and waiting times in the port area.	A simulation model to compare four alternatives. 1. A hub on the right river bank. 2. Creation of a hub on the left river bank. 3. Creation of a first multi-hub with a hub in the cluster of sea terminals on the left and right riverbank. 4. Creation of a multi-hub with hubs on both sides of the river bank.	The fourth scenario significantly reduces the turnaround time and leads to the optimal situation for the terminal and barge operator.
Major factors to be considered in the development of a hub and spoke network	Konings, Kreutzberger and Mara (2013)	Examine how container barge handling can be improved.	A cost model with a comparative analysis of the cost performance.	The hub and spoke network has a net benefit in the total hinterland chain of the barge transport, provided that the handling costs in the hub are not overstretched.
Multidisciplinary analysis behind the coordination problems in container barging in the port of Rotterdam	Van der Horst and Kuipers (2013)	To understand the reason for the difficulty in solving the coordination problems of barging and why container barging is still deficient.	A case study approach focused on inland barging activities at the port of Rotterdam.	Although many interdependent actors have different arrangements, these actors do not provide a sense of urgency to improve the situation.
Cost calculation model for inland navigation	Al Enezy, Van Hassel, Sys and Vanelslander (2017)	Calculate the specific cost for barge transportation, including the cost of waiting time, congestion, external, variable, and fixed costs.	A generic cost calculation to address the shortcoming of the existing models and applications.	Utilizing models for inland navigation should depend on a specific company's input factors.
Closed-loop coordination of inland vessel operations in large seaports by using a hybrid logic-based benders decomposition.	Li et al., (2017a)	To address two of the coordination problems persistent in waterborne transport in large seaports.	Simulated coordination model using a logic-based bender and large neighborhood search.	The coordination approach could lead to a 10%-15% reduction in the time spent in the port for inland barges while reducing the waiting time at the terminals by 24%-35%.

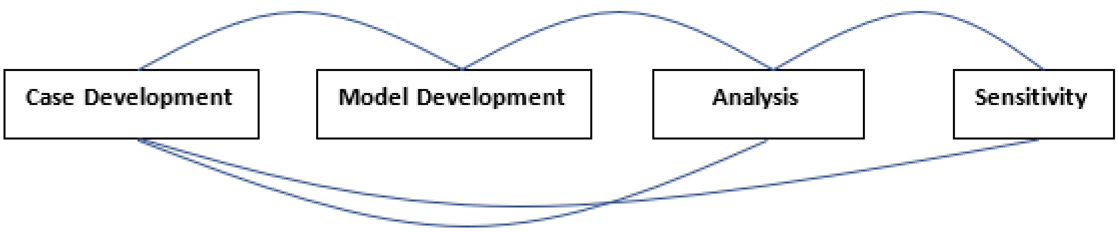
Planning of inland vessel operations in large seaports by using a two-phase approach.	Li et al., (2017b)	To reduce congestion of inland vessels and optimum utilization of terminal resources at the port.	Integrating mixed-integer programming with constraint programming develops rotation plans for inland vessels.	The proposed two-phased approach could benefit both vessel operators and terminal operators. It provides a better rotation plan for inland vessels, reducing their waiting time at the terminals and the time spent in the port areas.
Closed-loop scheduling and control of waterborne AGVs for energy-efficient inter-terminal transport	Zheng, et al., (2017)	To develop waterborne AGVs for energy-efficient inter-terminal transport	Simulation of the possibility of using waterborne autonomous guided vessels	A positive potential for the use of applying waterborne AGVs for inter-terminal operations.
Container barge (un)reliability in seaports: a company case study at the port of Antwerp.	Oganesian, Sys, Vanelslander, & van Hassel, (2021)	To provide a proposed optimization of container barge handling in a large seaport.	Variance analysis to examine the reliability issues. A total logistical cost to examine the transport-economic effect on shippers.	Unreliability is still a significant issue for container barging. This can be linked to a lack of contractual relationships between the barge operators and the deep sea terminals.

The studies, however, did not consider the underlying cause of poor handling in the sea terminals. This has been identified as the low priority given to container barges (Chapter 2). This low priority gives interfering deep-sea vessels a high priority to be first handled, leading to poor handling, high waiting time, and high congestion levels for the container barges. With this, it becomes vital to factor in the priority levels of container barges within the modeling approach. It examines whether optimizing the priority level would help improve barge handling, thereby reducing the congestion level in sea terminals. Based on this, the current study addresses the research gap identified by developing an agent-based model (ABM), which considers the priority issues of container barges as a parameter within the model. In doing this, the study proposes three scenarios and identifies the optimum scenario concerning container barge handling and congestion in sea terminals. To do this, the methodological approach is first examined. This is discussed in the next section.

4.2 Methodological approach

A quantitative methodological approach is adopted to answer the earlier identified research question based on four interrelated steps (Figure 4.1).

Figure 4.1: Methodological approach

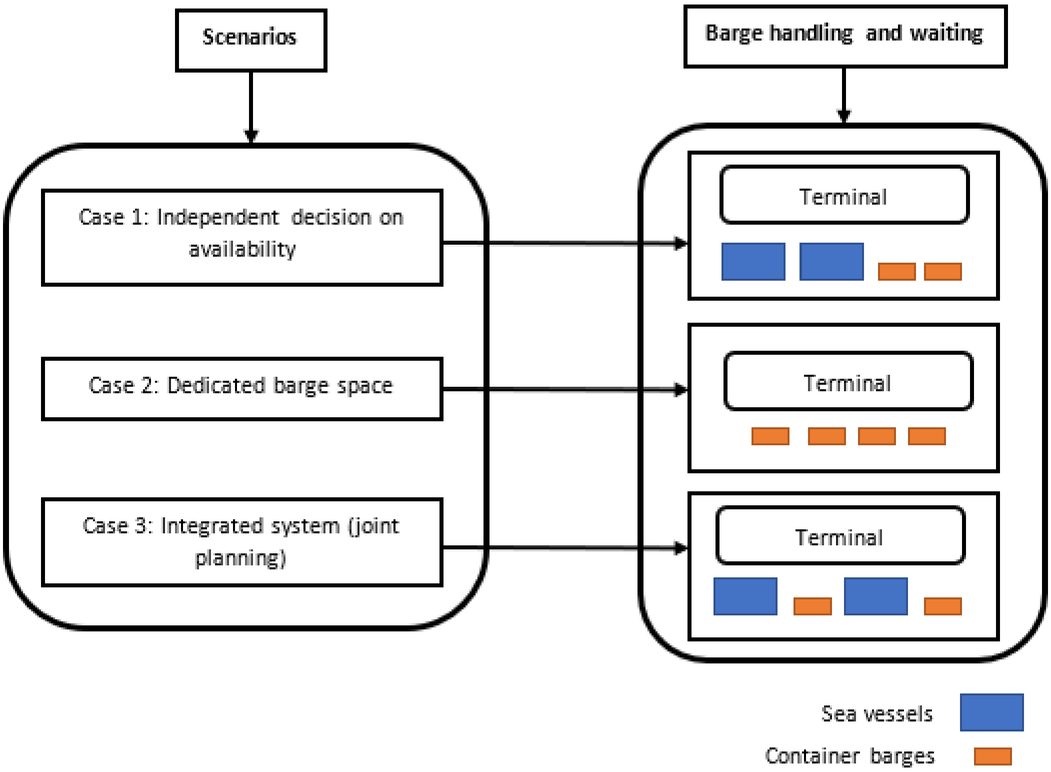


Step 1 focuses on developing three main cases based on the conceptual and practical understanding of container barge handling and congestion in sea terminals. Step 2 develops the agent-based model based on the highlighted cases and parameters. Meanwhile, step 3 analyses the model output and examines the impact assessment of the cases developed. Finally, step 4 conducts a sensitivity analysis of the identified cases. The three steps are further discussed in the following subsections.

4.2.1 Step 1: Development of cases

The three cases developed for this study are based on the insights derived from the literature and the survey conducted on the practicalities of container barge operations. Figure 4.2 presents the graphical description of the cases.

Figure 4.2: Case description



The first case examines the situation of barge congestion and handling in sea terminals when each terminal operator decides on its capacity and availability to plan slots for handling the container barges. This is the current situation; deep-sea vessels have priority in this case due to their contractual relationship with the terminals. Hence, the deep-sea vessels are handled before the barges, even if the barges are the first to arrive. This means the container barges will have to wait either until the deep-sea vessels are handled or wait for an opening or a time window. This consequently affects the sailing plans and schedule of the container barges.

The second case examines the scenario where the container barges have their dedicated handling space and terminal infrastructures without the interference of the deep-sea vessels. In this case, the vessels (deep-sea vessels and container barges) have their respective handling terminal berthing space. Meanwhile, the third case examines the handling time and congestion with integrated planning among the terminal operator. The container barges have a higher priority than the first case but are still lower than the deep-sea vessels. This implies that although the barges and deep-sea vessels share a common terminal space (quay), and the deep-sea vessels still have priority, the terminal operators try to handle the container barge as soon as possible. If this is not possible, they tend to move the barge to a free terminal at the time based on the planning and schedule of the new terminal. To do this, the terminal operators have an integrated system where they can see the terminals' schedules.

4.2.2 Step 2: Model development

In line with the cases developed in step one, an agent-based model (ABM) is designed to analyze the impact of each of the cases on the congestion level and, subsequently, the waiting time of the barges.

As earlier stated, researchers have used different models to examine the container barge handling and congestion issues in sea terminals. However, as much as these models are intended to solve the congestion and handling issues, they have not been able to capture the priority levels of container barges in deep-sea terminals. This priority level has been identified as one of the main parameters of container barge congestion in deep-sea terminals. Therefore, this study contributes to research by integrating this parameter within the ABM to examine how the barges react to the different priority levels. The ABM is considered a suitable modeling technique for this type of analysis because it simulates the interaction and reaction of agents under different circumstances in a behavioral environment (Reis, 2014). Based on this, the ABM is further discussed in the following subsection.

4.2.2.1 ABM Model

The ABM technique considers a system that consists of the interaction of agents within an environment that supports the existence of the agents (Bonabeau, 2002). An agent can be classified as an independent entity with specific objectives, display autonomous behavior and sense and communicate. Successful utilization of ABM depends on three major components: the agents, the interaction among them, and the environment in which they exist.

An agent could have complete or incomplete information about its surroundings and may be able to influence others around the environment. The interaction among agents focuses on how the agents communicate with each other to get information and act based on the information gathered. At the same time, the environment is a physical location that allows for the agents' interaction (North & Macal, 2007). The overall properties of a system are related to the dynamic interactions of the agents in the system. This determines whether an agent is pursuing a specific objective or reacting to a particular action. Thus, ABM follows a bottom-up approach to understanding the real-world situation.

The ABM approach has some advantages over the traditional modeling approach, such as the ability of ABM to generate an unlimited number of agents. The ABM approach allows one to model and study each agent's interaction. Finally, the ABM approach is dynamic. Here, the system and the agents can store and recall events (Reis, 2014). Some studies have used ABM principles to provide solutions to transport-related studies. For instance, Fischer, Kuhn, Müller, Müller, & Pischel, (1995) examine if the ABM principles help understand negotiation and cooperation dynamics in the road freight transport market. They conclude that the ABM approach is valuable in understanding and solving scheduling problem complexity. Baindur & Viegas (2011) conduct an ABM to support public policy designs and promote intermodal short-sea transport. They conduct a scenario analysis with the ABM. They concluded that each public policy determines a fixed regulatory layer constant over the experiment period.

Although the ABM model displays clear advantages in understanding the behaviors of agents compared to other models, some limitations can affect the accuracy of results compared to real-world events. Firstly, the high complexity of ABM in modeling the diverse interactions among agents. This complexity requires high computational accuracy and makes it difficult to generate an accurate model result representing real word events.

Secondly, a large amount of data is required to capture all the interactions among the agents, which can be impossible to gather, especially for container IWT operations in seaports. Thirdly, the ABM also requires numerous calibrations and validations to ensure that the output represents the real-world system. Finally, the ABM is also typically used for exploratory and scenario analysis rather than for precise predictions about future events. This makes the behavior and interaction of individual agents rather stochastic, which could sometimes lead to unpredictable outputs.

Despite these weaknesses, the ABM remains valuable for understanding the underlying behavior of a complex system, as it provides a framework for analyzing different alternative scenarios and identifying the underlying mechanisms that drive a system's behavior. This chapter aims to identify the underlying factor affecting container barge congestion in seaports. The ABM model provides an appropriate modeling framework for this chapter in that due to the lack of detailed data on container barge operations. The ABM could use the little available data to develop scenarios and understand the simple interactions among the identified agent. It also determines which scenario would produce an optimal solution for barge congestion without necessarily generating precise, accurate, statistically detailed results on the model output.

Based on this, the ABM is used in this research in an exploratory capacity to understand the container barge congestion issue in seaports based on their priority level. It is also used to determine which scenario could provide an optimal solution for container barges and under which condition the scenario will be optimal.

The model does not capture the in-depth technical details of the complex operations of container barges, deep-sea vessels, and sea terminals. The model intends to set a foundation for further analysis based on the recommended optimal scenario. The model simplifies the interaction between agents (sea terminals, deep-sea vessels, and container barges). This is presented in Figure 4.3. Although the model captures only the simple interactions among the terminal and barge agents, the research ensures that the model output still represents real-world situations. This is done by organizing a workshop with a barge operator (WeBarge, formally known as ibarge) to present the model output and get feedback on whether the outputs are relatable in practice. The feedback from the workshop was then used to calibrate the model and generate new output. The new outputs were presented in a second workshop with the same barge operator to get their final thought on the functioning of the model and outputs generated.

Figure 4.3: Model interaction between agents

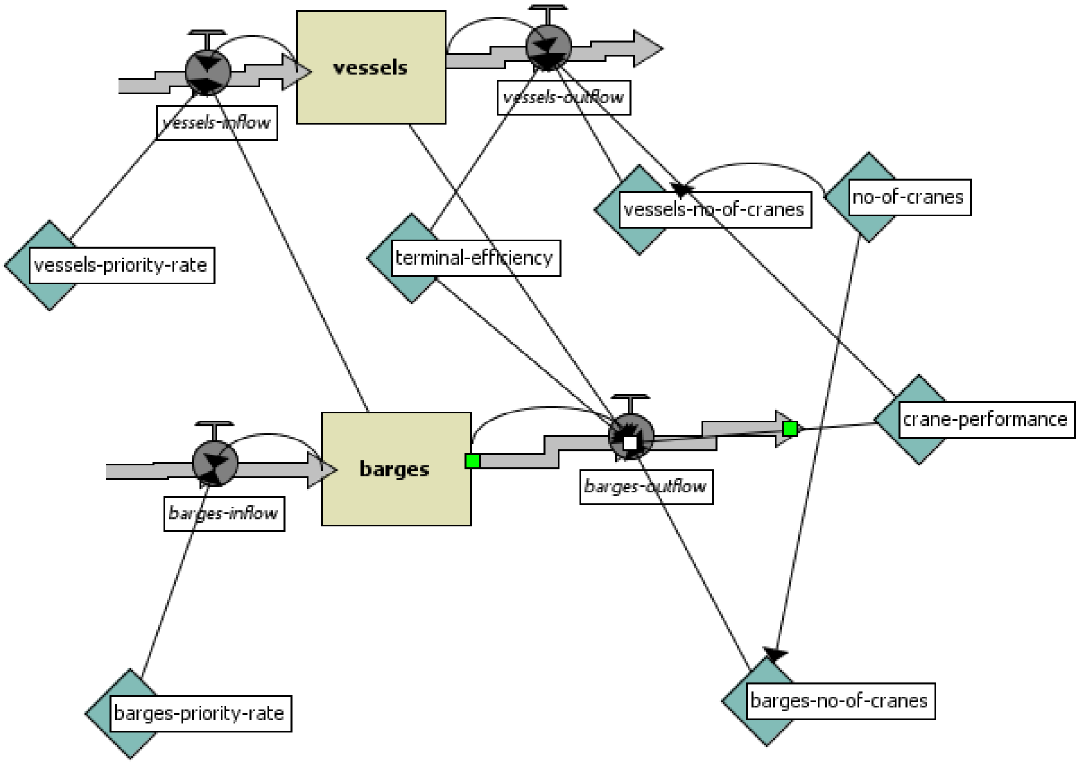


Figure 4.3 explains the relationship between the agents. The vessel inflow represents the rate at which new deep-sea vessels enter the system. This depends on the vessel priority rate, the number of deep-sea vessels, and the number of container barges already in the system. The vessel and barge slider set the number of deep-sea vessels and container barges in the system to 3 for both agents. This number is, however, calibrated in line with the different cases. On the other hand, the vessel outflow depends on several factors, such as the number of deep-sea vessels in the system, the terminal efficiency, the cranes allocated to each vessel, and the crane performance. These parameters are calibrated according to the different cases and the sensitivity analysis.

The barge inflow depends on the container barge priority rate and the number of barges in the system. In contrast, the barge outflow depends on the number of container barges and deep-sea vessels in the system, the terminal efficiency, the cranes allocated to the barges, and the crane performance. Terminal operations involve the total number of cranes available at the terminal, the allocation of cranes between the deep-sea vessels and the container barges, the crane performance, and the terminal efficiency. From the model, the vessel inflow is determined by the priority rate. The priority is explained as the vessel's chance to be handled as soon as possible at the terminal. A slider between 0.1 to 1.0 is used. In this slider, 0.1 implies a 10% chance that a vessel is handled as quickly as possible, whereas 1.0 implies a 100% chance of this happening. This analogy is also performed on the barge inflow and terminal efficiency. However, 0.1 implies a 10% terminal efficiency rate (low efficiency) for terminal efficiency, while 1.0 implies a 100% terminal efficiency rate (high efficiency).

The vessel priority rate determines the number of cranes allocated to vessels and the total number of available cranes at the terminal. A slider sets the available cranes in the model. Thus, the allocated cranes assigned to deep-sea vessels are the vessel priority rate multiplied by the number specified in the crane slider set in the model. Therefore, the higher the priority rate, the more cranes are allocated to the deep-sea vessels. The total number of cranes is set by a crane slider between 0 and 100. Crane performance, meanwhile, is specified by a crane performance slider that ranges between the values 0.1 to 1.0, where 0.1 implies a 10% performance level representing poor performance, and 1.0 indicates 100% performance representing high performance.

The model simulates the number of container barges handled at a terminal as a function of the priority rate and the inflow of sea vessels visiting the terminals. Meanwhile, the outflow rate of container barges is a function of the number of barges in the system, the number of deep-sea vessels being handled, the number of cranes reserved for barges, and the terminal efficiency. To ensure simplicity, the model captures only a part of the operational observation of the terminals, which deals with congestion and handling. This is captured within the model by giving more priority and allocating most of their resources to the deep-sea vessels. Based on this, the technical and operational activities of the terminals (such as the planning, crane, and gang allocations) are not captured within the model.

4.2.2.2 Data for ABM

The data used to analyze the cases is generated from the output of the agent-based model. The model is developed based on the information derived from barge operators (ibarge) and terminal operators (MPET) on barge activities in the port of Antwerp. The data collected relates to the terminal efficiency, crane performance, and the estimated number of container barges and deep-sea vessels handled monthly.

Based on the information collected, some assumptions were made in the model. Concerning the size and capacity of the vessels in the model, container barges are assumed to have an average length of 110m, an average width of 11.4m, a draught of 2.5m, an average capacity of 200 TEUs, and an average call size of 20 TEUs/terminal. On the other hand, deep-sea vessels are assumed to have an average length of 360m, an average width of 53.6m, an average capacity of 16,000 TEUs, and an average call size of 2000 TEUs. These assumptions are based on discussions with terminal operators (MPET) about the average vessel size that visited their terminal in 2018.

The model is subject to three levels of the validation exercise. The first is the requirement validation (a reflection of a real-world scenario). Second is the theory validation (valid assumptions in line with the operational practices of container barge handling, communication, and information sharing). The third is process validation (a clear and meaningful interaction among agents that correspond to real-world processes). These validation exercises reveal high validity in the input parameters specified within the model.

As explained, three cases are analyzed, each examining the container barge congestion situation from different circumstances. Based on this, the model parameters are adjusted to determine the resultant effect under each case. Table 4.2 presents the three cases and the parameters specified for each case.

Table 4.2: Parameters for defined cases

Case	Parameters	Values
Case 1: Independent decision on availability	Vessel priority rate	0.9
	Barge priority rate	0.1
	Number of barges at time step zero	10
	Number of vessels at time step zero	3
	Terminal efficiency	80%
	Crane performance	35 moves per hour
	Number of cranes	20
Case 2: Dedicated barge space	Vessel priority rate	0
	Barge priority rate	0.5
	Number of barges at time step zero	10
	Number of vessels at time step zero	0
	Terminal efficiency	80%
	Crane performance	35 moves per hour
	Number of cranes	3
Case 3: Integrated system (joint planning)	Vessel priority rate	0.9
	Barge priority rate	0.5
	Number of barges at time step zero	10
	Number of vessels at time step zero	3
	Terminal efficiency	80%
	Crane performance	35 moves per hour
	Number of cranes	20

Case 1 - an independent decision on capacity and availability

This is the base case of the current situation at the terminals. In this situation, the deep-sea terminals make independent decisions on their capacity and availability. In doing this, they prioritize sea-going vessels due to their contractual relationship. Therefore, the vessel priority rate is set to 0.9 (90% probability that it would be handled quickly). The container barge priority rate is set to 0.1 (10% probability of being handled in time). The initial number of container barges at step zero within the model is set at 10, while the number of deep-sea vessels is set to 3. This implies that at step zero, ten container barges and three deep-sea vessels await handling. The terminal efficiency, in this case, is set to 0.8 (80% efficiency performance), which implies a high efficiency. Finally, crane performance is assumed to make 35 moves per hour, while the number of cranes is 20.

Case 2 - dedicated space and infrastructure for barges

This case simulates the situation of container barges with a dedicated barge space and three cranes available to handle the barges in the reserved area. For this case, the initial number of container barges in the system at step zero is 10, and the priority rate is set to 0.5 (50% being quickly handled). This value is a worst-case probability for unforeseen circumstances such as gang unavailability, delay in time slots or schedules, and other extreme external factors. There are no vessels and priority rate, as this case is solely reserved for container barge operations. Finally, the terminal efficiency and crane performance remain constant as in the base case.

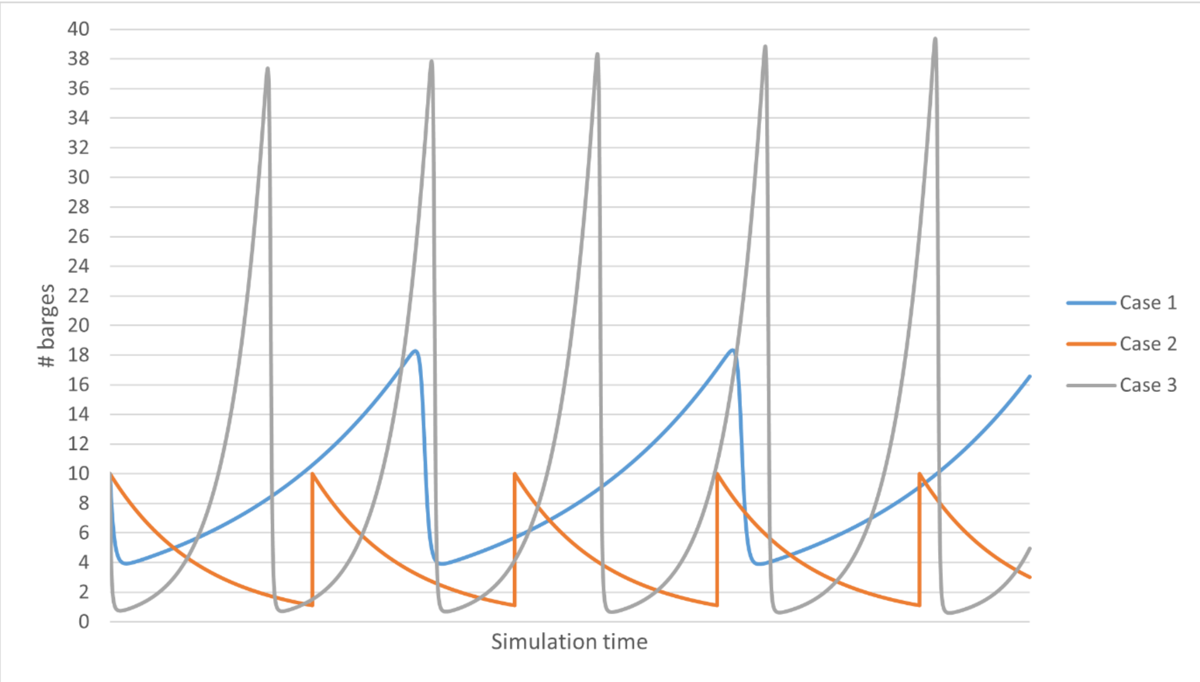
Case 3 - integrated planning and higher priority for barges

This case examines the situation if the terminal operators do joint planning and prioritize the container barges while also maintaining the high priority of the seagoing vessels. In this case, the priority rate of the barges is increased to 0.5 (50% chance of being quickly handled), while the deep-sea vessels still maintain the initial priority rate of 0.9 (90% chance of being swiftly handled). The number of cranes remains 20, while the initial number of container barges and deep-sea vessels at step zero remains 10 and 3, respectively. The main difference between this case and the base case is the significant increase in the priority rate of barges, as the terminal operators are assumed to give them more importance, which means they are handled as soon as possible. All stakeholders have joint and integrated planning to ensure they are attended to quickly.

4.3 Analysis and Discussion

The results of the three cases are presented in this section; afterward, sensitivity analysis is conducted to see the effect of the adjusted parameters on the solution. The simulation model is conducted on Netlogo, with a simulation runtime of 50,000 ticks for each case. Figure 4.4 presents the output of barge congestion buildup for the three cases.

Figure 4.4: Barge congestion output



As seen in the figure, all three cases have the number of barges set as 10 in the simulation system. A reduction in barges from ten to four can be observed for the first case. However, the handling rate also drops as the number of barges reduces. This is due to the focus on deep-sea vessels, affecting vessel handling rate. When the number of barges eventually drops to four, no barges are handled. Full attention is given to the deep-sea vessels, leading to the potential build-up of container barges and, consequently, a high waiting time for the barges.

There will always be four container barges in the system because, at this point, all available crane capacity is allocated to the deep-sea vessels currently waiting in the system. The barges then remain in the system while more barges join the queue. This leads to a build-up up to a certain level (18 in case one). Once this level is reached, the system then allocates cranes to start handling the barges to reduce the congestion level within the system. This cycle continues throughout the simulation run.

Hence, the maximum number of barges in the system in case one is eighteen, while the minimum number, in this case, is four.

For case 2 (dedicated space and infrastructure for barges), the same process applies; however, as there is no deep-sea vessel interference, in this case, the cranes are continuously deployed to the container barges, leading to a reduction of the barges in the system. With this, the maximum number of barges waiting in the system does not exceed the initial set value of 10, while the minimum value of barges, in this case, is one. This implies no congestion/waiting issues for container barges in this case.

The third case, which focuses on the integrated planning for the terminal operators, reveals that an increase in the priority rate of the container barges would further lead to an increase in the barge build-up, hence congestion within the system. This implies that increasing barge priority while there is still deep-sea vessel interference would not reduce the congestion situation of the barges but rather compound it, suggesting the significant effect of vessel interference on the barge congestion situation in seaports.

4.4 Sensitivity analyses

Based on the preliminary analysis of the three cases. Sensitivity analyses were further performed to examine how barge build-up and congestion would be impacted by changes in some of the earlier parameters identified in each case. The changes in these parameters are presented in Table 4.3.

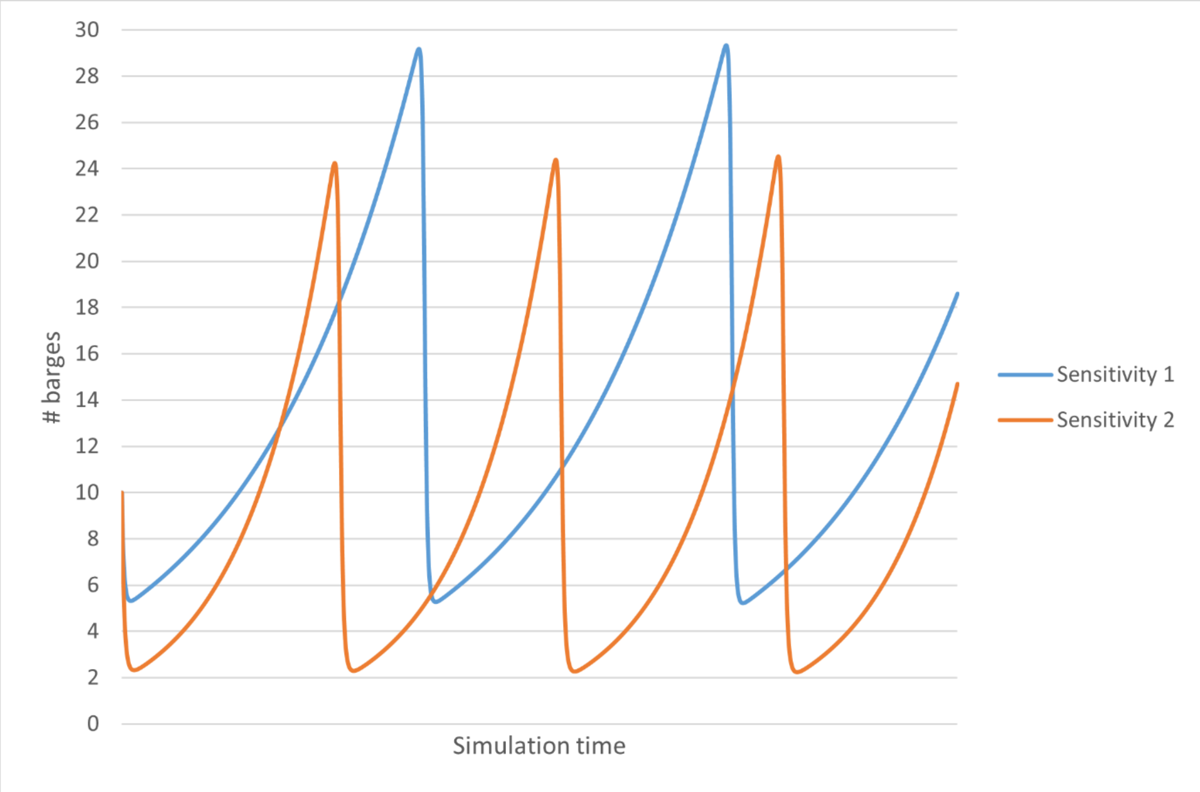
Table 4.3: Parameters for sensitivity analysis

Case	Sensitivity	Parameters	Values
Case 1: Independent decision on availability	Sensitivity 1	Vessel priority rate	0.9
		Barge priority rate	0.1
		Number of barges at time step zero	10
		Number of vessels at time step zero	3
		Terminal efficiency	80%
		Crane performance	35 moves per hour
		Number of cranes	30
	Sensitivity 2	Vessel priority rate	0.8
		Barge priority rate	0.2
		Number of barges at time step zero	10
		Number of vessels at time step zero	3
		Terminal efficiency	0.8
		Crane performance	35 moves per hour
		Number of cranes	20
Case 2: Dedicated barge space	Sensitivity one	Vessel priority rate	0
		Barge priority rate	0.5
		Number of barges at time step zero	10
		Number of vessels at time step zero	0
		Terminal efficiency	80%
		Crane performance	35 moves per hour
		Number of cranes	2
	Sensitivity two	Vessel priority rate	0
		Barge priority rate	0.5
		Number of barges at time step zero	10
		Number of vessels at time step zero	0
		Terminal efficiency	80%
		Crane performance	35 moves per hour
		Number of cranes	4

Figure 4.5 compares the sensitivity analysis in the parameter changes for case one. In this case, the first sensitivity examines what would happen if the number of cranes is increased to 30 while holding other parameters constant. The output reveals that increasing the number of cranes without necessarily increasing the priority of container barges would further compound the barge congestion situation at the terminal. The extra cranes will be deployed to handle more deep-sea vessels while the barge build-up becomes longer. This output suggests that as long as there is sea-vessel interference in container barge operations, increasing the number of cranes will not necessarily reduce barge congestion/waiting time in sea terminals but rather intensify the situation.

The second sensitivity analysis examines the situation if the priority rate of deep-sea vessels is reduced to 80%), whereas that of the container barges is increased by 10%. Results reveal a similar trend with the first sensitivity, where container barges' congestion and waiting issues persist. The figure suggests that an increase in either the priority rate of container barges or the number of cranes at a sea container terminal would not resolve container barge congestion issues if there is still interference of deep-sea vessels in barge operation in the terminal. Deep-sea vessels are always prioritized due to their agreements with terminals. This further justifies the use of a dedicated handling space for terminal operations.

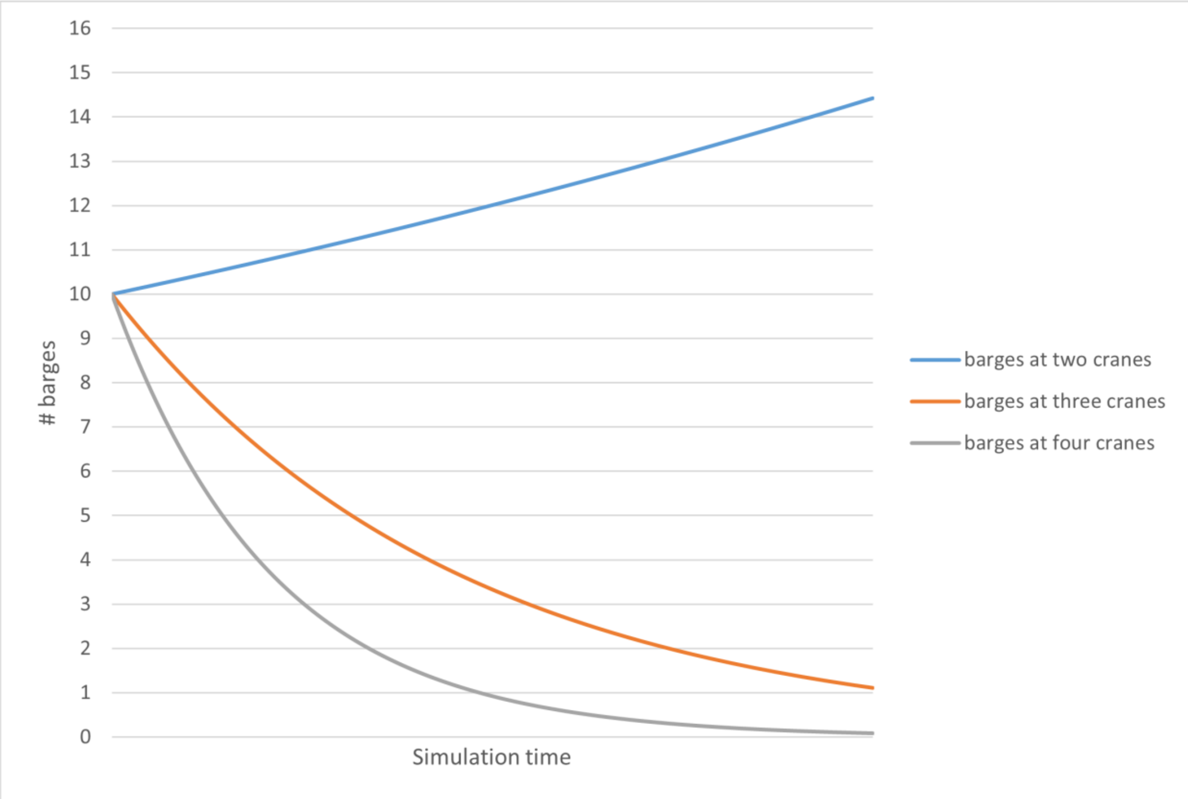
Figure 4.5: Sensitivity output of barge congestion



Having established from the previous analyses that dedicated handling space is needed to reduce container barge congestion in sea terminals, Figure 4.6 presents how the number of cranes could affect barge congestion and wait at the dedicated terminal space. Results reveal that having one or two cranes in the dedicated area is not optimal for reducing barge congestion, even if the container barges have their space and are not disturbed by the interference of the deep-sea vessels. This is due to the service frequencies between the seaports and the hinterland regions connected to these ports via IWT transport. This ensures that multiple container barges call at a terminal simultaneously. This implies that having just one to two cranes to handle container barges at the dedicated space at a time would mean that the other barges would have to wait, causing a delay in the system and eventually leading to congestion.

The figure further suggests that having more cranes in the dedicated space will reduce container barges' congestion. The question now begs, at which point will an optimal number of terminal cranes serve the barges? This question will be studied in detail in the next chapter. For this chapter, the simulation analysis reveals that an additional crane would further reduce container barges' build-up and waiting time in sea terminals.

Figure 4.6: Sensitivity output on the number of cranes



4.5 Synopsis

This chapter examines the handling and congestion of container barges at sea terminals in seaports with hinterland connections. It investigated a base case and two alternative scenarios to resolve the challenges identified with barge handling and congestion. A system dynamic agent-based modeling was developed to examine the three scenarios and determine the optimum scenario to reduce congestion and enhance barge handling.

A general phenomenon deduced from the analysis is that the combination of deep-sea vessels and the number of allocated cranes to the barges determine how long the container barges would wait at each terminal. This implies that not only do the container barges need dedicated spaces within each terminal, but they also need the appropriate number of smaller cranes that can efficiently handle them in the dedicated space; otherwise, the problem of congestion and handling would persist.

The analysis reveals that the case with dedicated barge space offers the best solution to the congestion and handling issues. In this sense, if the terminals can create a dedicated handling space and invest in suitable infrastructures for the container barges, it could significantly reduce the waiting time of the barges and ensure that they do not spend an extended period at the terminals. With this, a shorter lead time could lead to more reliability and supply chain flow optimization.

In as much as investing in dedicated barge handling infrastructure is the most promising option to reduce barge congestion, there is concern about this type of investment's financial and operational feasibility. What would be the cost-benefit of investing in this solution for all actors? Hence, more research is needed, focusing on the capital and operating cost of dedicated barge space and the operational profile of this solution (such as the possibility of bundling and consolidating). These will be answered in the next chapter, focusing on the operational and economic feasibility of the dedicated barge space for the identified actors (terminal operators, barge operators, and shippers).

Chapter 5 - The economic analysis of dedicated barge space solution

5.1 Introduction

This chapter aims to answer the second part of RQ2: Analysis of the Mobile terminal concept as a solution for dedicated barge space. Based on the recommendation from Chapter 4, the current chapter examines the economic feasibility of having a dedicated container barge space solution for container handling and consolidation[6]. It has been established in previous chapters that container barges experience high waiting time, congestion, and poor handling in sea terminals due to low priority and low call sizes at these terminals. Based on this, the current chapter examines how to resolve the challenges by reducing port sailing and waiting times for barges through a dedicated barge space without expensive modifications to port infrastructures.

A floating terminal concept called the Modular Mobile Terminal (MMT) is proposed to achieve this. An assessment methodology is developed to evaluate its potential operational efficiency for providing consolidation and distribution stations for container barge handling. This station could be placed on the land, but developing a floating terminal concept could bridge this gap considering the intensive land use in most ports. The MMT will be the interface where an inland waterway vessel (IWV) can deliver and collect containers to and from the seaport terminals.

Similar ideas have been conceived in the past. Examples include the “container transferium” (Konings, van der Horst, Hutson, & Kruse, 2010). This initiative is a consolidation point for cargo coming from the hinterland and going to the port and vice versa. It is suggested that the location of this facility should be in the direct hinterland of Rotterdam. Although its main goal is to serve trucks to decrease congestion on the port’s highways, it can also be used by inland shipping. The transport between the transferium and the sea terminals is then assured by shuttle barges. These shuttles would have dedicated quays at sea terminals. They could perform a round trip (visiting all sea terminals) or be assigned to a specific terminal (Froeling, van Schuylenburg, Groenveld, & Taneja, 2008). More recently, a Transport and Logistics floating hub not located in the hinterland but at sea was proposed within the Space@Sea project. The feasibility of the concept was assessed by simulating sea-going inland vessels calling at this offshore hub and feeder vessels linking the hub to the sea terminals. It was found that the concept was economically feasible if inland vessels directly go to the hub without stopping at the sea terminals (Assbrock, Ley, Dafnomilis, Duinkerken, & Schott, 2020).

Furthermore, a thorough technical evaluation of a so-called Floating Container Storage & Transshipment Terminal was proposed by Baird & Rother (2013). The authors state that the most promising configuration is to fit a crane on a converted container ship. They argue that this concept is technically feasible in a low-wave sheltered environment and that the investment can be covered in much less time than a conventional on-shore terminal (Baird & Rother, 2013).

[6] This chapter will be published as Nicolet, A., Shobayo, P., van Hassel, E., & Atasoy, B. (2023). Development of a modular terminal concept for container barging in seaports: a time and cost assessment methodology.

Malchow further takes the floating crane concept and proposes a Port Feeder Barge for inter-terminal transfers in seaports (Malchow, 2020). It consists of a self-propelled container barge equipped with a mounted crane. Besides intra-port operations, the author suggests that the Port Feeder Barge can also be used as a floating terminal for inland vessels. The Feeder would perform a round trip to the deep-sea terminals to collect/deliver containers shipped to/from the hinterland. The inland vessels would then directly visit the Port Feeder Barge instead of deep-sea terminals. Compared to additional land-based facilities, the solution offers advantages regarding implementation costs, simplicity, and environmental impacts. The author nevertheless points out that the defiance of terminal operators represents a significant obstacle as they are reluctant to delegate container handling operations to external actors.

Based on all these previous studies, the proposed MMT concept offers a good compromise as the crane module is situated separately, thus not directly interacting with the deep-sea terminals. Containers are stacked on modules and then conveyed to the terminals that keep the crane handling operations from the modules to the yard. In addition to the evident advantages for barge operators, this concept allows terminal operators to plan their operations more effectively, as incoming cargo will already be consolidated. This would result in a win-win situation, which is essential to get the commitment of all stakeholders (Caris, Macharis, & Janssens, 2011).

Regarding methodology, the existing works have used several means to assess the efficiency of the proposed solution. Some present a cost-benefit analysis to evaluate the economic possibility of the concept (Konings, 2007; Konings, Kreutzberger, & Maras, 2013), while others make use of simulations to assess the concept's operational feasibility (Assbrock, Ley, Dafnomilis, Duinkerken, & Schott, 2020; Froeling, van Schuylenburg, Groenveld, & Taneja, 2008). The other studies mainly focus on the technical components (Baird & Rother, 2013), discuss the offered possibilities and managerial insights without numerical results (Konings, van der Horst, Hutson, & Kruse, 2010), or combine these two approaches (Malchow, 2020).

This chapter contributes to the body of knowledge through a unified methodology combining technical, operational, and economic aspects. Indeed, an economic assessment model is developed to determine the economic feasibility of the MMT concept and financial gains for both the barge operators and the shippers. Consequently, the MMT concept is evaluated based on two indicators: the ability to significantly reduce the waiting time of container vessels and enhance cargo bundling without necessarily leading to extra costs for the additional movement of cargoes.

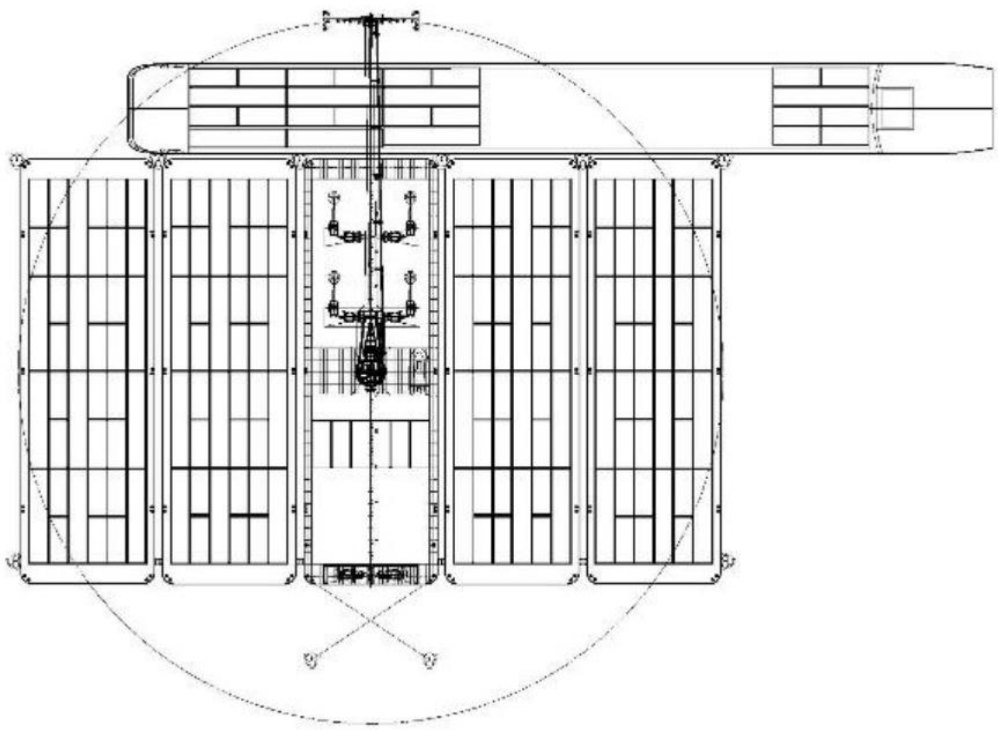
The remainder of this chapter is structured as follows: section 5.2 describes the MMT concept. Section 5.3 specifies the impact analysis of the MMT concept for the identified actors. The assessment methodology is discussed in section 5.4 and applied to a case study for the ports of Antwerp and Rotterdam in section 5.5 Some practical implications were discussed in section 5.6. Finally, section 5.7 presents the model transferability conditions, while section 5.8 presents the intermediate conclusion of the chapter.

5.2 MMT concept description

This section presents the most important aspects of the proposed Modular Mobile Terminal concept[7]. The MMT proposed in this study is made up of modules. The modules are configured as a dumb barge that can either be pushed or towed between the mobile terminal handling area and the sea terminals. The MMT modules will be operated in the seaport area and have no reason to move upstream and pass narrow locks. Based on the aforementioned technical reports, the dimensions of the modules are 17m in width and 55m in length. Moreover, a cargo capacity of 138 TEUs per module is specified for this concept.

As depicted in Figure 5.1, a Modular Mobile Terminal comprises four modules coupled to a central module with a mounted crane. It is estimated that the crane will make up to 20 container moves per hour and that the MMT crane module has a capacity of 124 TEUs. When assembled into a Modular Mobile Terminal, all the modules will have a mooring system to create a rigid connection between the barges. This rigid connection will increase the stability of the coupled units providing less heeling movements during cargo handling.

Figure 5.1: Modular Mobile Terminal in action



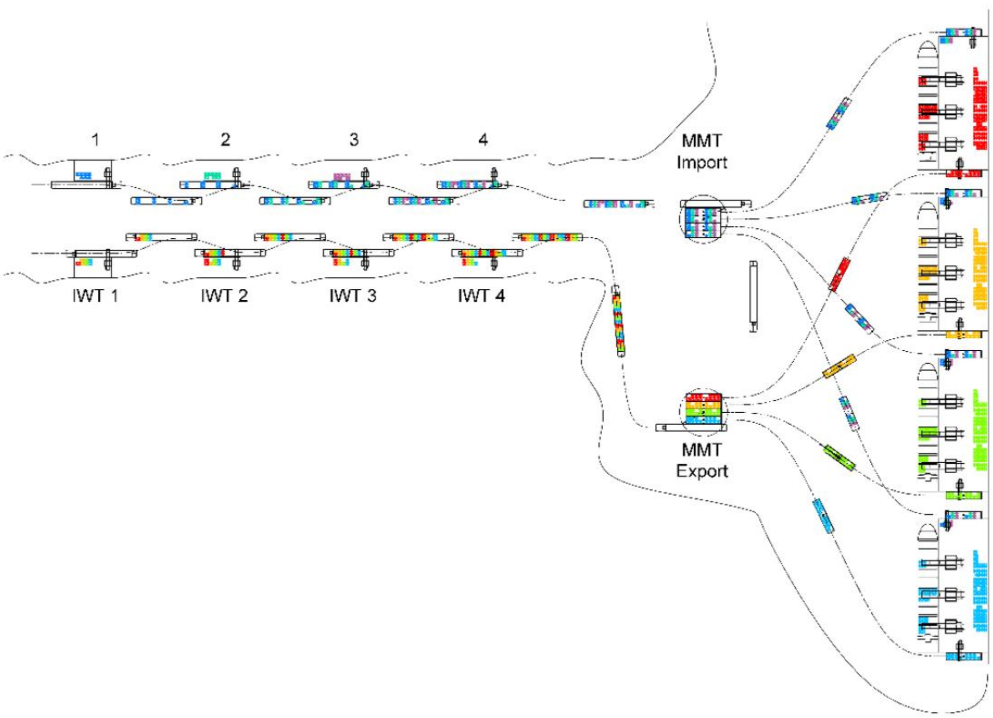
Source: Thill et al., (2022)

The envisaged operation of the system is that inland waterway vessels collect containers from the inland ports. The container cargoes have different destinations, i.e., different seaport terminals. When

[7] For more detailed information, the reader is referred to the following technical reports (Ramne, et al., 2021; Thill, et al., 2022).

the IWV reaches the seaport, instead of calling at different terminals to drop and pick up containers as it is currently, the IWV will moor at the Export MMT (Figure 5.2). The crane module will be the center point of the operation, unloading the IWV and distributing the cargo to the shuttle modules. Once the shuttle modules are sufficiently loaded, they are towed/pushed by a push boat to transport the containers to the specified seaport terminal. Each module will make a dedicated call to a single seaport terminal where the containers can finally be unloaded. The shuttle modules will also transport import cargoes by transporting containers from the seaport terminal to the import MMT, where the modules are moored. At the import MMT, the crane module will transfer the cargo from the shuttle modules to an IWV for transport to the destination inland port, as shown in Figure 5.2.

Figure 5.2: Envisaged operation of the MMT concept[8]



Source: Ramne et al., (2021)

As mentioned earlier, the technical feasibility of a floating crane has already been demonstrated in the Port Feeder Barge project. However, the economic factors were not detailed in-depth, and this project suffered from the defiance of terminal operators (Malchow, 2020). Based on this, the concept within the Port Feeder Barge project was not further pursued (UG, 2021; Soyka, 2020). The MMT concept proposed in this chapter is similar to the Port Feeder Barge. However, to prevent similar a setback, the potential benefits for the logistics actors are carefully highlighted in this study. In particular, this work aims to dive further into the logistical and economic aspects of the modular terminal. The expected benefits of this innovation will be demonstrated via an economic assessment model. Based on this, it is important first to identify the actors and how the mobile terminal operations

[8] Although this illustration shows MMTs operating at separate locations, the import and export handling can be arranged at the same location.

in ports will impact them. After this, the final goal will be to understand this concept's advantages for the identified actors from the economic viewpoint.

5.3 Impact analysis of the MMT system for actors

This section identifies the key actors in the MMT operations in seaports and assesses how the implementation of MMT might impact them. Based on the envisaged operations of the MMTs in Figure 5.2, the potential main actors of this system are identified as sea terminal operators, mobile terminal operators, seaport, barge operators, and shippers. Each of the actors' roles and possible impact on their operations is discussed below:

Sea terminal operators: Implementing the MMT in seaports will affect the planning of the terminals as they have to create fixed and dedicated slots for the shuttle transport of consolidated containers between the MMT and the terminals. This might affect the deep-sea vessels' planning and require careful planning and extra management effort to implement this operation. Further investment in additional terminal facilities might also be needed for this type of operation as they will now need to handle large volumes in a terminal visit compared to the small volume in the base case. This might prevent terminal operators from integrating this into their system, especially if they are unwilling to make further investments.

Nevertheless, sea terminals could enjoy some benefits from using this system. One of the biggest benefits is the increased flexibility and efficiency that will be enjoyed with this system. Because containers are now consolidated and transported in one go, with one shuttle barge rather than different barges with smaller volumes, they are better handled more quickly and efficiently, leading to a streamlined and improved service for their customers. Another benefit of using this system for terminal operators is the fixed guaranteed revenue stream generated from the regular container volumes and fixed slots for shuttle transport. This guaranteed revenue stream could make the system self-sustaining for the terminal operators. It could even generate some revenue for further investment and expansion without relying on revenues from other business sources. This could lead to a whole new business model for the terminal operators.

Mobile terminal operators: The success/failure of the MMT implementation particularly depends on who would take the initiative to invest in this solution (known as the mobile terminal operators) and the business model that will be used for this concept. One major opportunity that could be derived from the MMT solution is the ability to offer a lasting solution to barge congestion in ports that have plagued the sector for a long period. This could position the MMT operator as a major player in port barge logistics and create a whole new business concept in which the MMT creates a niche market for its operation, yielding a high return on revenue if successfully implemented. However, as much as economically promising this concept could be for the MMT operator, some challenges could prevent its operation and profitability.

First is the restriction in the port area regarding where the system could be placed, the working conditions, and the overall requirements that must be fulfilled before it can be operational. This could be a tedious task that could affect market uptake and prevent entrepreneurs from investing in it.

Secondly, consolidating and transporting containers would require that the MMT system be integrated with the sea terminal system and other established port systems. This complex process requires a lot of back-and-forth communication and information sharing. An information breakdown could lead to container tracking errors, derailing the system's overall operation.

Another challenge to the profitability of the MMT system for MMT terminal operators has to do with the physical structure and characteristics of the MMTs. The MMTs require significant investment in specialized mobile equipment and technology, requiring highly skilled operators. Also, increased use of the MMT would lead to higher maintenance costs and the need for frequent equipment replacement due to wear and tear. These could lead to revenue loss and increased transshipment/consolidation costs, making it less attractive for barge operators/shippers to use. This could lead to a bad investment for the MMT operators if they cannot generate the steady cash flow needed to make the system self-sustaining.

Seaports: The ports are not directly impacted on by the MMT implementation. They have more of an advisory and regulatory role to play in ensuring the smooth implementation and operation of the MMTs. Nevertheless, they still enjoy some benefits of using this system within the port. For instance, container barges will no longer sail further into the port area to visit multiple terminals. This will reduce terminal visits, reducing the congestion level of container barges in ports. Furthermore, the MMT concept reduces the waiting time for container barges in ports. This could further enhance the efficiency of port activities.

Barge operators: The MMT concept would directly impact on barge operators by increasing their efficiency and reducing terminal waiting times. The container barges do not have to visit multiple terminals and are better handled with this system, ensuring a quick handling process and a faster turnaround time. This would increase the reliability of container barge transport, thereby enhancing the competitiveness of this mode. However, barge operators could be challenged with the additional transshipment costs associated with this system. This would lead to an increased cost, thereby discouraging the barge operators from using the system.

A further challenge to the barge operator is the risk of delay and congestion in ports that might be encountered if numerous barges make use of this dedicated space solution. Hence, implementing this system requires detailed planning and analysis of the number of MMTs to be invested in, the type of market to focus on, and the arrival pattern of the vessels in the target market in the port.

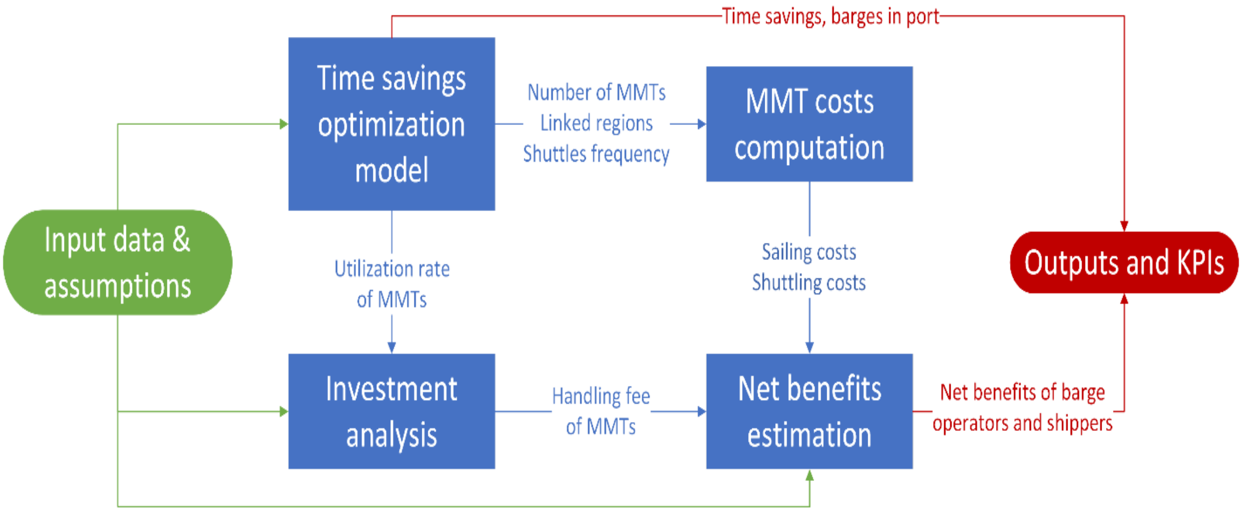
Shippers: The shippers could transport goods more quickly, as the MMT system could lead to a faster turnaround time for the container barges. This could lead to reduced costs for the shippers, thereby allowing them to enjoy more competitive transport rates. However, for this to be the case, the MMT system needs careful planning and management to ensure that the MMTs are effectively integrated into the port environment. An error in container tracking or handling could delay the container, thereby running the risk of a demurrage and detention fee. This could quickly lead to a high and unbearable cost for the shippers.

Having analyzed the benefits and challenges of the MMT system for each actor, it is necessary to analyze the economic viability of this system as a whole and determine the net benefit of the main actors involved (specifically the MMT operator, barge operator, and shippers).

5.4 Assessment methodology

The proposed methodology approaches the MMT concept from the time and cost perspective. To be effective, the MMTs should generate time savings for inland waterway vessels sailing between the deep-sea terminals and the hinterland. They must also be economically viable for the barge operators and the shippers. Figure 5.3 shows the main steps of the assessment methodology: firstly, an optimization model computes the number of MMTs, frequency of shuttles, and linked regions that maximize the overall time savings of the vessels. This time optimization model is based on the research of Nicolet, Shobayo, van Hassel, & Atasoy (2023). Outputs from this model are then used to estimate the costs induced by the MMTs per region. Next, the time optimization model also returns the utilization rate of MMTs under the optimal configuration. This rate is then used in the investment analysis to determine the handling fee that should be charged to make the investment profitable. This handling fee is used with the MMT-related costs to estimate the net benefits of using the MMTs compared to the base situation (i.e., without MMTs).

Figure 5.3: Proposed assessment methodology



Source: Nicolet et al., (2023)

Based on this, the following subsections present the approach behind the MMT concept, its envisaged operations, and the economic assessment model.

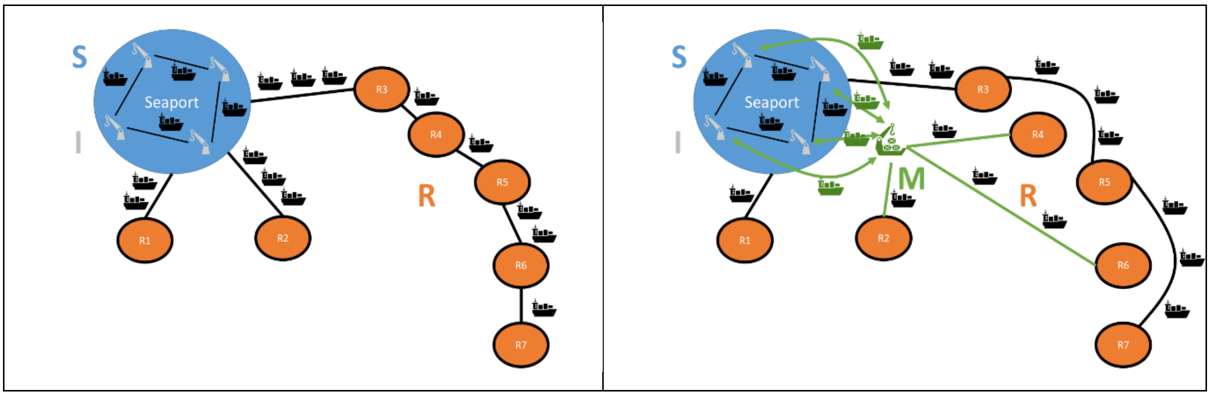
5.4.1 Modular terminals operations

The MMT concept is applied to a seaport environment, denoted S, and its hinterland. The former is represented as a set of sea terminals I and the latter as a set of regions R. Each region has a given container transport demand via IWT to and from the seaport and some IWT services to satisfy it. Each IWV performs a roundtrip between the region and the seaport. In the seaport area, it has to sail between multiple sea terminals to load and unload containers.

The MMTs, denoted M, are considered to be located near the seaport area and linked to some of the hinterland regions: then, all containers to and from these regions are handled by the MMTs. For regions not linked to the MMTs, the operations of each IWV will not change compared to the base case. However, the vessels serving the linked regions will no longer call at the sea terminals but only at the MMTs. Push barges between MMTs and sea terminals will then shuttle the MMT modules[9]. This concept is illustrated, together with the base case, in Figure 5.4.

[9] It is assumed that modules will have dedicated spots at sea terminals, thus they experience no waiting time.

Figure 5.4: Schematic representation of -base case scenario (left) and situation with MMTs where regions 2,4,6 are linked (right)



Source: Nicolet et al., (2023)

Based on Figure 5.2, the MMTs will operate in pairs: one export MMT and one import MMT. Moreover, each module of an MMT is associated with only one specific sea terminal. The IWVs from the hinterland will first moor at the export MMT to unload their containers. When empty, they can moor at the import MMT, where containers from the seaport to the hinterland can be loaded. Finally, they will unmoor to sail back to the hinterland.

Regarding the shuttles, once a module of the export MMT is full, it is detached and shuttled to its dedicated sea terminal, where the containers are unloaded. Then containers with a destination to the hinterland are loaded, and the module is shuttled back to the import MMT, replacing an empty module. Finally, the empty module is returned and attached to the export MMT.

5.4.2 Economic assessment model

This section presents the economic models developed for the MMT case. The investment, cost, and cost savings models are discussed. The parameters used in these models are presented in Table 5.1.

Table 5.1: Model parameters

Notation	Unit	Description
$\boldsymbol{t_{rS}}$	[hr]	Sailing time between hinterland region r and seaport area.
$\boldsymbol{t_{M}^{wait}}$	[hr]	Waiting time at MMT for an inland vessel.
$\boldsymbol{t_{M}^{hand}}$	[hr/TEU]	Handling time at MMT per container.
$\boldsymbol{t_{MM}^{man}}$	[hr]	Manoeuvering time between import and export MMTs.
$\boldsymbol{t_{MS}^{sail}}$	[hr]	Sailing time between MMT and seaport area, incl. maneuverings
$\boldsymbol{t_{i}^{hand}}$	[hr/TEU]	Handling time at deep-sea terminal i per container
R_t	€	Net cash flow (inflow-outflow) in a single period *t.*
r	%	Discount rate/WACC.
t	Years	The number of periods.
F_c	€	Cash flow.
R_L	€	Loan repayment.
x^*	€	The optimum handling price that can be charged.
$O(x)$	€	The upper-bound handling price.
x	€	The lower-bound handling price.
$C_{\frac{tot}{teu}r,i,k}$	[€/TEU]	Total cost per TEU between region r and terminal i for month k.
$C_{\frac{tot}{hr}r,i,k}$	[€/hr]	Total costs per hour between region r and terminal i for month k.
$T_{t\ r,i,k}$	[hr]	Total transport time between region r and terminal i for month k.
$n_{TEU\ r,i,k}$	TEUs	Number of TEUs transported between region r and terminal i for month k.
$C_{total,mto}$	[€/TEU]	The total cost of using the mobile terminal as transshipment.
C_{mt}	[€/TEU]	Cost of sailing and handling at the mobile terminal.
C_{sdt}	[€/TEU]	Cost of using the shuttle and sailing to a specific deep-sea terminal.
$C^{mt}_{\frac{tot}{trip}}$	[€/trip]	The total cost of sailing to and handling at the mobile terminal.
$C_{\frac{fix}{trip}}$	[€/trip]	Total fixed cost.
$C_{\frac{var}{trip}}$	[€/trip]	Total variable cost.
$C_{\frac{fuel}{trip}}$	[€/trip]	Total fuel cost.
C_{fix}	€	Fixed cost.
T_{port}	hr	Port time.
T_{idle}	hr	Idle time.
$C_{maintenance}$	€	Maintenance cost.
$C_{\frac{fuel}{l}}$	[€/litre]	Fuel cost per liter.
F_{sail}	Litre	Total fuel consumed sailing.
F_{idle}	Litre	Total fuel consumed idle.
$\boldsymbol{x_{k}^{in.ex}} \in \mathbb{N}$	-	The number of import and export terminals visited.
$C^{sdt}_{\frac{tot}{trip}}$	[€/trip]	The total cost of shuttle transport from the mobile terminal to the sea terminal.
$\boldsymbol{t_{MS}^{port}}$	hr	Port time of shuttle barges between the mobile and sea terminals.
$\boldsymbol{t_{ms}^{wait}}$	Hr	Waiting time of shuttle barges at the sea terminals
S_o^b	[€/TEU]	Cost savings of the barge operator per trip
S_s	[€/TEU]	Cost savings of shippers per trip.
$\overline{q}$	[€/TEU]	Aggregated cost savings for actors per case.
$\sum_{ij} x_{ij}y_{ij}$	€	Sumproduct of cost savings per region per month weighted against the total volume transported per region per month.
$\sum y_{ij}$	TEUs	Total TEUs transported for all months and regions.

The economic assessment model is specified to estimate the overall net benefit of each actor and determine what conditions would generate overall cost savings from using the MMTs. The cost model is represented in three parts. The first part focuses on the investment analysis of the MMTs. Meanwhile, the second and third parts focus on the cost computation and net benefits of both the barge operators and shippers.

5.4.2.1 Investment analysis

The investment analysis calculates the Net Present Value (NPV) of the MMTs handling and transshipment operations. This type of analysis is the generally used method to determine the viability of a project by calculating the current and future cash flow, capital investment, and terminal values generated within a given project. This is calculated as:

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+r)^t}$$ *Equation 1*

$$R_t = F_c - R_L$$ *Equation 2*

R_t, F_c, and R_L are calculated based on specified steps. The steps are presented in Table 5.2 based on the specification of van Hassel (2011) and De Langhe (2019). According to the table, the first step is to derive the total operating income for the MMT. This income includes all revenues from operating the mobile terminal. Step two is to determine the total cost of operating the MMT. This consists of the maintenance, labor, and variable technological costs. Next is calculating the overhead cost, including insurance, legal fee, and marketing cost. After this, the earnings before interest, tax, depreciation, and amortization (EBITDA) is calculated by subtracting the operational and overhead costs from the operating revenue.

In step 5, the depreciation is calculated by dividing the capital and fixed technological investments invested over the project's life span. This result is subtracted from EBITDA to give the operational effect in step 6. Step 7 calculates the interest payable per year by multiplying the loan by the interest on the loan. The result is subtracted from the operational result to give earnings before tax in step 8 (EBT). In step 9, the payable tax is calculated. Tax can only be calculated if the EBT is greater than 0; otherwise, no tax is charged on the investment. The deductible tax is derived by multiplying the EBT by the specified company tax rate in the country. This leads to step 10, the earnings after taxes (EAT).

Step 11 calculates the investment's cash flow by adding EAT (step 10) with depreciation (step 5). The payback loan for the project is then calculated in step 12 by dividing the initial loan by the payback period of the loan. This leads to step 13, where the net cash flow is obtained. This is derived by subtracting the payback loan (step 12) from the cash flow (step 11).

Table 5.2: Investment analysis steps

10	Items	Calculation
1	Revenues	Operational income
2	Operational cost	Maintenance + labor + variable technological cost
3	Overhead cost	Insurance + legal fees
4	EBITDA	1 – (2 + 3)
5	Depreciation	Capital and fixed technological investments/project lifespan
6	Operational result	4 – 5
7	Interest	Loan * interest on the loan
8	EBT	6 – 7
9	Tax	If 8 <= 0, 0; otherwise 8 * tax rate
10	EAT	8 – 9
11	Cash flow (F_c)	10 + 5
12	Loan repayment (R_L)	Loan/payback period
13	Net cash flow (R_t)	11 – 12

Source: Own composition based on van Hassel (2011) and De Langhe (2019).

For this type of project, a 6% discount rate is deemed appropriate, as it is considered a long-term investment with an average life span of 30 years (van Dorsser, 2015). Moreover, this rate is considered a common standard for evaluating long-term projects. It provides a reasonable benchmark based on historical data and reflects the long-term average returns on equity and debt investments. The rate also provides a consistent and objective way to compare investment projects across various industries and sectors.

The overall objective of the MMT operator in this type of investment is to generate a positive NPV, which would ensure that the costs of investment are covered while also yielding a positive return. Hence, to ensure a positive NPV, an optimization technique is performed on the NPV calculation that iterates through the cost elements, the rate of return, and the potential net cash flow. This iteration generates an optimal handling price to generate a positive revenue stream that can cover the different cost levels (capital and operating costs), ensuring a positive NPV. To achieve this type of iteration, a while loop was created that iterates over the handling price, corresponding cash flows, and the WACC and returns the corresponding NPV and rate within the iteration. If the NPV remains negative, the loop continues by adding 10% to the current handling price and rerunning the cashflows and the NPV until it reaches an optimum handling price that returns a positive NPV as long as the optimum price is not greater than the set upper bound price. A simple representation of this iteration loop is specified below:

$x = x^*$ *Equation 3*

$while\ x < O(x)$: *Equation 4*

$$step\ 1: \sum_{t=0}^{n} \frac{R_t}{(1+r)^t}$$ *Equation 5*

$$step\ 2: if \sum_{t=0}^{n} \frac{R_t}{(1+r)^t} > 0:$$ *Equation 6*

$break$

$step\ 3: x = 1.1x$ *Equation 7*

$return\ x\ and\ NPV$

where $O(x)$ is the estimated price charged at the sea terminal. This is specified as EUR 41.01 per TEU from the model of van Dorsser (2015). The lower bound handling price, however, is the minimum handling price of the mobile terminal without a markup margin. This price is calculated based on the capital and operating costs and the actual utilization rate estimated within the investment model. These cost elements are derived from Ramne et al. (2021) in the cost description of the mobile terminal concept.

5.4.2.2 MMT costs computation

The second part of the cost representation deals with the cost estimation of transporting the containers from the selected regions to the seaports. This analysis is performed for the two cases (base case and concept case). For the base case, the analysis elaborates on the cost implication of transporting from the linked regions directly to the sea terminals. This analysis is represented as follows:

$$C_{\frac{tot}{teu}r,i,k} = \frac{C_{\frac{tot}{hr}r,i,k} * T_{t\ r,i,k}}{n_{TEU\ r,i,k}}$$ *Equation 8*

where $C_{\frac{tot}{hr}r,i,k}$ entails the fixed and variable costs, while $T_{t\ r,i,k}$ comprises the sailing time, port time, and idle time. Detailed specifications on these parameters are discussed in Shobayo, Nicolet, van Hassel, Atasoy, & Vanelslander (2021). Meanwhile, $n_{TEU\ r,i,k}$ is the actual number of cargoes transported. This is based on the cargo flow between the OD region and the service level of the vessel.

The project case cost analysis elaborates on the cost implication of using the MMTs as a transshipment hub rather than having direct transport to the sea terminals. This calculation follows the same approach as the direct sailing analysis. However, significant changes occur in the time spent in port, thus affecting the total transport time. This is because using the MMTs means the container barges do not have to visit different sea terminals; instead, they sail to the import/export MMT pair to pick up/drop off containers. However, the cost of transporting from the MMTs to the specific sea terminal by shuttles must be considered (*Equation 9*). This is then factored in and specified as:

$$C_{total,mto} = C_{mt} + C_{sdt}$$ *Equation 9*

$$C_{mt} = \frac{C^{mt}_{tot/trip}}{n_{TEU/trip}}$$ *Equation 10*

$$C^{mt}_{tot/trip} = C_{fix/trip} + C_{var/trip} + C_{fuel/trip}$$ *Equation 11*

$$C_{fix/trip} = C_{fix} * (t_{rS} + T_{port} + T_{idle})$$ *Equation 12*

$$C_{var/trip} = C_{maintenance} * (t_{rS} + T_{idle})$$ *Equation 13*

$$C_{fuel/trip} = C_{fuel/l} * (F_{sail} + F_{idle})$$ *Equation 14*

$$T_{port} = \left(t^{wait}_{M} * x^{in.ex}_{k} \in \mathbb{N}\right) + \left(n_{TEU\, r,i,k} * t^{hand}_{M}\right) + t^{man}_{MM}$$ *Equation 15*

$$T_{idle} = 0.1 * (t_{rS} + T_{port})$$ *Equation 16*

$$C_{sdt} = \frac{C^{sdt}_{tot/trip}}{n_{TEU/trip}}$$ *Equation 17*

$$t^{sail}_{MS} = t^{sail}_{MS} * 2$$ *Equation 18*

$$t^{port}_{MS} = \left(n_{TEU\, r,i,k} * t^{hand}_{i}\right) + t^{wait}_{ms} + t^{man}_{MM}$$ *Equation 19*

The cost of sailing and handling at the mobile terminal is specified as the total cost per TEU of sailing and handling at the mobile terminal (*Equation 10*). This cost comprises the fixed cost per trip, variable cost per trip, and fuel cost per trip (*Equation 11*). To estimate the fixed cost per trip, a specified fixed cost is multiplied by the total transport time of the vessel (*Equation 12*). The transport time comprises the sailing time from the hinterland region to the seaport area (see **Appendix D**), the port time, and the idle time (*Equation 12*). The port time includes the waiting time at each terminal multiplied by the number of import-export mobile terminals, the handling time per TEU multiplied by the number of TEUs transported, and the manoeuvering time at the mobile terminals (*Equation 15*). The idle time in the model is specified as the time that the vessel's engine is running without any operation on the vessel, either sailing or handling (*Equation 16*). This time is estimated at 10% of the port and sailing times based on van Dorsser (2015) model. The specified fixed cost is estimated at EUR 86.64 based on calculations from van Dorsser (2015) and Shobayo et al., (2021) models. The variable cost per trip is specified as the cost of maintenance multiplied by the sailing time and the idle time (*Equation 13*). Meanwhile, the fuel cost per trip is estimated by multiplying the fuel cost per liter by the fuel consumption while sailing and idle consumption (*Equation 14*).

The same approach was applied to the shuttle transport cost per trip from the mobile terminal to deep sea terminals, with significant changes to the sailing time and port time (*Equation 17*). In this case, the sailing time is when the shuttle service sails back and forth to the sea and mobile terminals (*Equation 18*). In contrast, the port time includes the waiting time at sea terminals (assumed to be 0), the manoeuvering time, and the handling time of the containers at the terminal (handling time per TEU multiplied by the TEUs transported) (*Equation 19*).

5.4.2.3 Net benefits estimation

The third part calculates the barge operator and shippers' net benefits. In doing this, the base case is compared to the project case, and the net savings are estimated for the barge operators and shippers, respectively. These are specified as follows:

$$S_o^b = C_{tot/teu\,r,i,k} - C_{mt} - x^* \qquad \textit{Equation 20}$$

$$S_s = C_{tot/teu\,r,i,k} - C_{total,mto} - x^* \qquad \textit{Equation 21}$$

These cost savings are aggregated per case. To do so, the net savings per month per region are weighted against the transported volumes for that month and region. The total of these then gives a net benefit of the case for the linked regions and the months within each case. The total net benefit is divided by the total volumes transported within the case to get the aggregated cost savings per TEU. Based on this, the aggregated cost savings $\overline{q}$ is specified as:

$$\overline{q} = \frac{\sum_{ij} x_{ij} y_{ij}}{\sum y_{ij}} \qquad \textit{Equation 22}$$

5.5 Model application to case study

The proposed assessment methodology is applied to a case study, where the use of MMTs is investigated for the ports of Rotterdam and Antwerp. For both seaports, it is assumed that each inland waterway vessel has to visit four sea terminals, where the handling capacity is 20 TEUs per hour (thus a handling time of 0.05hr/TEU). The waiting time of an IWV at each sea terminal is estimated at an average of four hours during each terminal visit (van Hassel, et al., 2021), and sailing time between these sea terminals is set to one hour (including maneuverings). The data concerning hinterland container transport (using waterways) is reported in **Appendix D**. In particular, each seaport contains:

- the yearly import and export demand to and from each hinterland region represented at the NUTS-2 level[10];
- the distance of each region from the seaport;
- the sailing time between each region and the seaport;
- the yearly number of inland waterway transport services between each region and the seaport;
- and the average occupation rate of the inland waterway services.

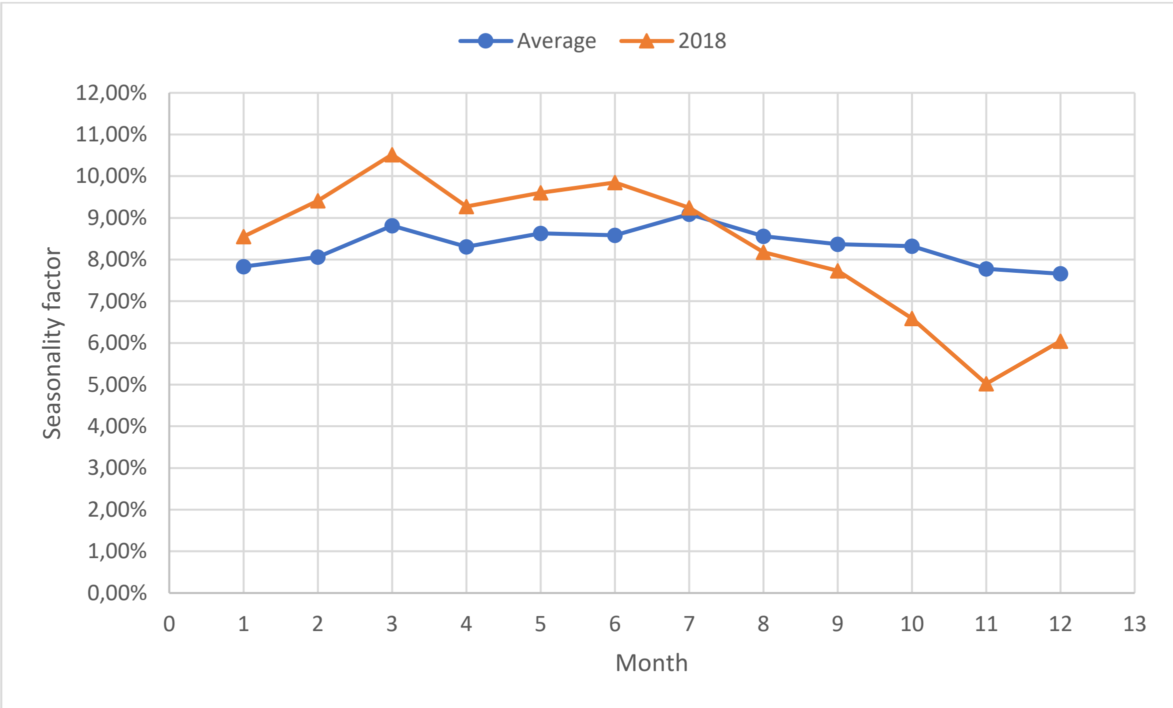
The container volume data come from the ASTRA model (Fiorello, Fermi, & Bielanska, 2010) for 2021. This demand is assumed to be split evenly between all the visited sea terminals. The distance is estimated by van Hassel et al., (2019). The sailing times are issued from a cost and time model (Shobayo, Nicolet, van Hassel, Atasoy, & Vanelslander, 2021), whereas the data concerning IWT services come from the NOVIMOVE project (Majoor, et al., 2021). Note that the number of monthly

[10] The NUTS is the official division of the EU and the UK for regional statistics (European Commission & Eurostat, 2020).

services is assumed constant and obtained by dividing the yearly services by twelve. Finally, the average occupation rate of the services is computed assuming an average vessel capacity of 256 TEUs.

Some seasonality factors are used to derive the monthly transport demand between each seaport and each region. They represent the share of the total demand in a given month and are estimated using historical data from container transport on the Rhine between 1993 and 2020 (Rhineforecast, 2021). Figure 5.5 shows the factors corresponding to a typical year and the ones corresponding to 2018, when a major drought occurred on the Rhine, thus disrupting transport via water with decreased capacities for container IWVs (van Dorsser, Vinke, Hekkenberg, & van Koningsveld, 2020). For a typical year, those factors remain relatively stable, varying between 7.6% and 9.1%. However, the interval is much broader for 2018 (between 5% and more than 10.5%), with a peak in demand in March but particularly a very low demand in the last quarter of the year due to the low water levels.

Figure 5.5 : Seasonality factors for an average year and year 2018, with high seasonality pattern



Source: Rhineforecast (2021)

Regarding the parameters related to the MMTs, each module is a capacity equal to 138 TEUs. The handling time of the crane module is set to 0.05hr/TEU, and its maximal handling capacity during a month to 10,000 TEUs. Each inland vessel is assumed to experience a waiting time of one hour before being handled both at the import and export MMTs. Moreover, a manoeuvering time of 15 minutes between the import and export MMTs is considered. The maximum number of MMTs allowed in the seaport is eight for both seaports, and the sailing time of shuttles between their sea terminal and the MMTs is estimated to be 1.65 hours for Rotterdam and 1.05 hours for Antwerp. These estimates are based on a preceding study that evaluated some locations potentially suitable for MMTs in these seaports (Freling, Nicolet, & Atasoy, 2022).

The MMT modules and cranes have an estimated life span of 30 years, with a capital cost of EUR 1,042,000 per MMT module, EUR 30,000 for spud poles per module, and a crane cost of EUR 940,000.

The MMT is estimated to have a residual value of 30% of the initial capital investment. Other operational costs include insurance, estimated at 2% of the capital investment; labor costs, assumed to be EUR 60,000 per year; and other overhead expenses, estimated at EUR 225,000 per year. An indexation rate of 1.4% and a profit tax of 33% are employed in the analysis. The costs are estimated by Ramne et al., (2021), while the operational assumptions are based on Shobayo, van Hassel & Vanelslander (2021), and van Dorsser (2015).

Using the inputs above, the optimal configuration of MMTs will be determined for both seaports for a typical year and a year with high seasonality to highlight the differences. The optimal number of MMTs could vary monthly to match the demand variations. Nevertheless, from a financial point of view, investing in an asset that will be underutilized or only be used for part of the year is not desirable. Hence, some sensitivity analyses are also performed, where the number of MMTs is fixed throughout the year. This experience is conducted for one, two, three, and four pairs of import-export MMTs to compare the performance of each configuration and evaluate the most favorable one.

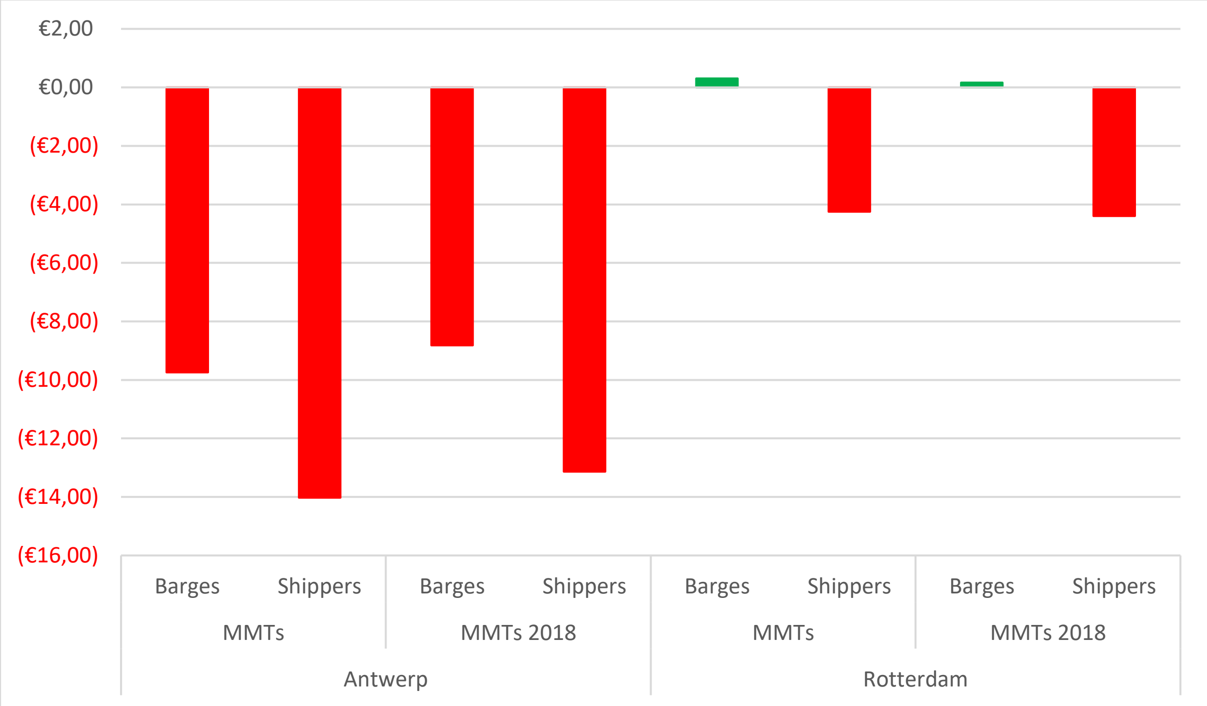
In the following sub-sections, the optimal solution (with a variable number of MMTs through the year) from the economic viewpoint is presented to get insights into the impact of MMTs. Secondly, the sensitivity analysis results with a fixed number of MMTs are reported. Finally, the practical implications are discussed in more detail.

5.5.1 Optimal solution

The economic implication of the MMTs is now examined. This is presented in Figure 5.6, where the aggregate benefit of the shippers and barge operators is determined for the two ports and the two cases. The figure reveals a negative overall economic benefit of using the MMTs for both ports' actors (shippers and barge operators). The negative economic benefit is more severe in Antwerp than in Rotterdam. For the former, the barge operators could experience a net loss of as high as EUR 10 per TEU, while for the shippers, this could reach EUR 14 per TEU. Rotterdam, meanwhile, performs slightly better, although still not economically favorable for shippers. In this case, the barge operators achieved a somewhat positive benefit of around 31 cents per TEU, while the shippers still realized a net loss of around EUR 4.

An observed reason for an aggregate net loss for the actors can be attributed to the average number of MMTs deployed each month. This number does not provide an optimal solution for the actors because some MMTs will not be utilized in a period of low demand, whereas some costs will be accrued for these MMTs. Therefore, the transshipment rate must be increased considerably for the terminal investor to cover these costs. This rate does not provide a favorable condition for the shippers and barge operators, as it will be too expensive for them, leading to a net loss.

Figure 5.6: Cost savings per TEU



Although the aggregate net benefit is negative for the actors in most cases, positive net benefits can still be achieved across the months for some individual regions. This means some regions would realize positive results even if the overall result becomes negative. This is useful to consider the specific impact of individual regions irrespective of the aggregate outcome of all regions. The practical implication of this is further described in section 5.6, where the redistribution mechanism of the benefit is explained. Based on this, Table 5.3 presents the number of regions that would yield positive net benefits for each case and port. The table reveals that the year 2018 case has a higher number of positive regions linked to the MMTs for both ports [11]. This implies that the higher the variation in the transport demand, the more feasible it is to use the MMTs. Based on this, it can be argued that the MMTs are suitable for dealing with container IWT transport flow disruptions. Furthermore, it can be observed that Antwerp generally has more positively linked regions than Rotterdam. This is, however, related to the fact that more regions are generally linked to Antwerp than Rotterdam due to the lower container volumes.

Table 5.3: Number of linked regions with a positive net benefit

Actor	**Antwerp**		**Rotterdam**	
	MMTs	MMTs 2018	MMTs	MMTs 2018
Barges	8	8	5	6
Shippers	5	8	4	5

Further analysis is shown in Table 5.4, where information regarding the total volume of cargo handled by the MMTs in each case and port is presented. The table also presents the average load of the vessels in these regions and the threshold of the TEUs per vessel required to achieve a positive net benefit.

[11] A detailed analysis of the specific regions can be found in Appendix E.

Starting with the annual cargo volume being handled by the MMTs, the table reveals that Rotterdam generally has more cargo volume handled than Antwerp. The high cargo flow from the connected regions can explain this. Nevertheless, handling high cargo volume does not necessarily lead to economic gains for the actors. This is due to the sub-optimal use of the MMT versus the number of connected regions.

A second observation in the table is the average payload of the vessels using the MMTs. It can be observed that the average number of TEUs per vessel falls between 65 and 75. This suggests that the MMTs are most suitable for small barges or vessels with low occupation rates and small call sizes. Although the average payload of vessels is low, this does not guarantee a positive business case for the barge operators and shippers. Therefore, a threshold on TEUs per vessel is computed to generate a positive net benefit. This figure is 46 TEUs for regions connected to Antwerp and around 60 TEUs for regions linked to Rotterdam. These are the maximum payloads of the vessels to guarantee positive net benefits for the barge owners and shippers. This implies that the suitability of using the MMTs is based on small call sizes of vessels (or small vessels), hence, a niche market for the MMTs.

Table 5.4: Annual volume passing through MMTs and volumes on container barges

	Antwerp		Rotterdam	
	MMTs	MMTs 2018	MMTs	MMTs 2018
Annual volume	588,190	494,481	764,453	716,496
Avg. TEUs per vessel	72	67	69	67
Threshold TEU number	46	46	59	56

5.5.2 Sensitivity analysis

The previous results show no economic benefit to using MMTs in the ports for the actors; hence a sensitivity analysis is conducted to determine under what conditions the MMTs will be economically viable. The sensitivity focuses on having a fixed number of the terminal rather than allowing this number to vary from month to month. The sensitivity analysis is conducted for a typical year (with low seasonality) to ensure that the MMTs will perform better in case of more pronounced seasonality. Table 5.5 displays the KPIs for the sensitivity analysis for the ports of Rotterdam and Antwerp.

Table 5.5: Results of sensitivity analysis

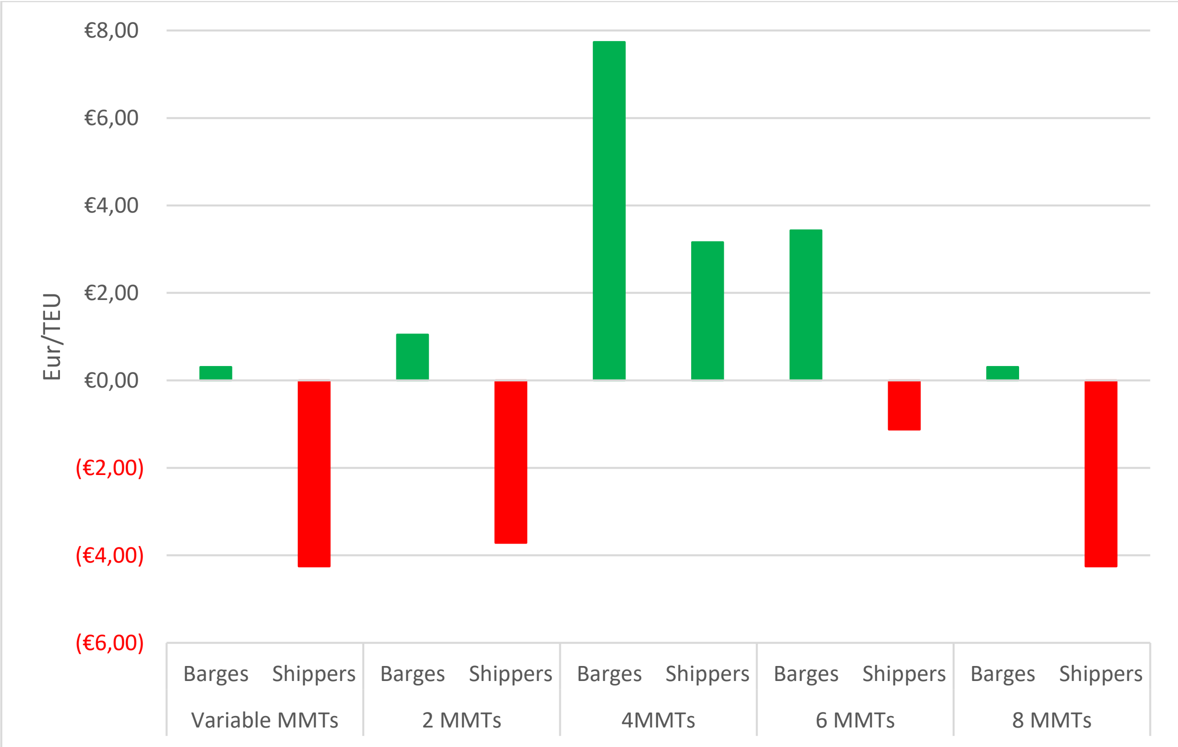
MMTs	**ROTTERDAM**				**ANTWERP**			
	2	**4**	**6**	**8**	**2**	**4**	**6**	**8**
NregionsS	2	4	4	4	8	5	5	5
Annual volume	169.978	373,369	564,437	764,453	167,428	292,801	429,613	583,986
Threshold load	54	56	59	59	51	46	46	46

Table 5.5 shows noticeable differences between Rotterdam and Antwerp for the KPIs, the results of which will be described separately in the following subsections.

5.5.2.1 Port of Rotterdam

Table 5.5 shows that using four MMTs generates the biggest cost savings for barge operators and shippers. This is demonstrated in Figure 5.7, where the benefit of barge operators could be as high as EUR 7.7 per TEU, while that of shippers could be as high as EUR 3.2 per TEU. These MMTs would generate an annual cargo volume of 373,369 TEUs with a threshold payload of 56 TEUs for the container barges. Based on this, five hinterland regions with positive net benefits will be connected to these MMTs from the barge operators' viewpoint. In comparison, four hinterland regions will be linked from the shippers' viewpoint.

Figure 5.7: Cost savings per TEU for Rotterdam

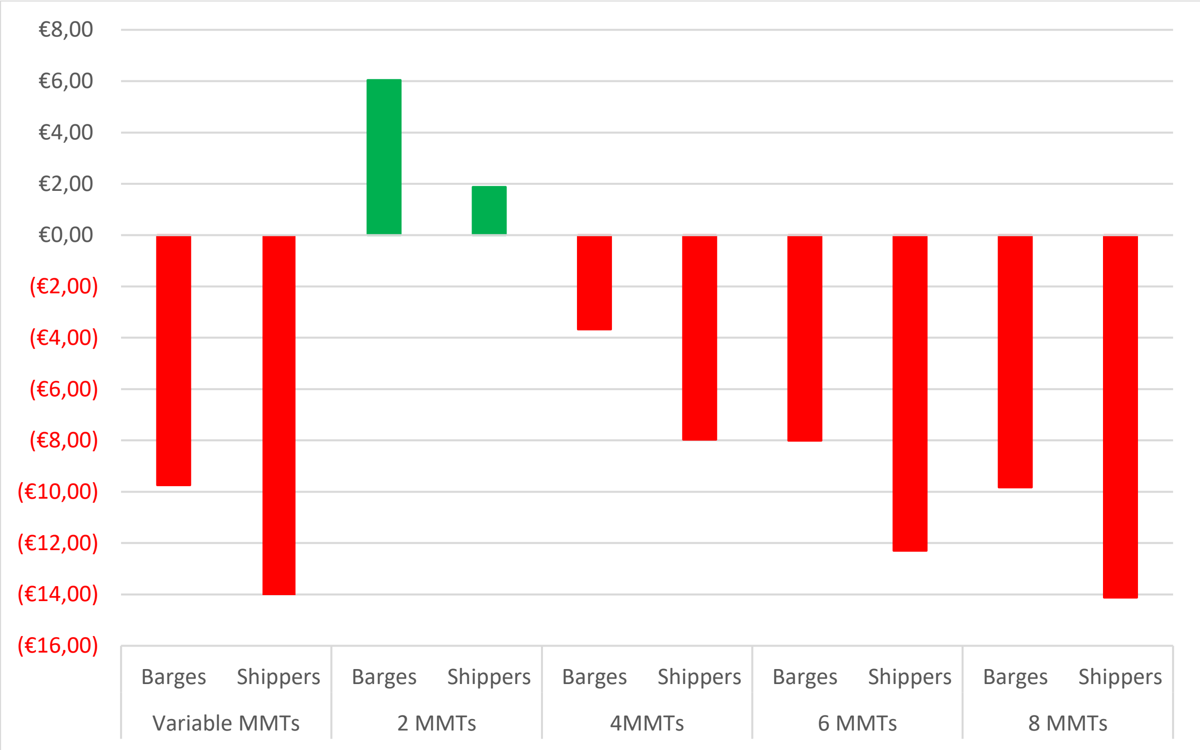


In general, the results support that installing four Modular Terminals (two for import and two for export) would provide the biggest benefits for the Port of Rotterdam. It would give maximal time savings for inland vessels while significantly reducing the congestion in the port. From the cost perspective, it also provides the biggest economic benefit for the barge operators and the shippers. Finally, having four MMTs installed would ensure that the MMTs are optimally utilized and always deployed at any time of the year.

5.5.2.2 Port of Antwerp

In the case of Antwerp, installing two mobile terminals would lead to only positive net benefits for actors compared to the other cases (Figure 5.8). In this case, the net benefit of barge operators will be as high as EUR 6 per TEU, while for shippers, it will be as high as EUR 2 per TEU. All other situations would lead to a net loss for the actors in the port of Antwerp, making two the optimal number of MMTs. These two MMTs will be able to handle 167,428 TEUs annually. This justifies why the MMTs are most suitable for small call sizes of inland container vessels. This analysis determined that vessels with a payload lower than 51 TEUs will be most suited to use the MMTs.

Figure 5.8: Cost savings per TEU for Antwerp



For all these reasons, deploying two Modular Terminals (one for import and one for export) is sufficient for the port of Antwerp. It is indeed the most favorable case for all the considered KPIs.

5.6 Practical implications

Based on the specified parameters, the developed model shows some interesting insights that could be implemented in practice. Firstly, it allows insights into the optimal number of MMTs to invest in for the two ports in question (two for Antwerp and four for Rotterdam). This is interesting from the investment viewpoint, as strategic decisions can be made based on this. For instance, regarding the location of MMTs, it would be easier to install two MMTs in the port of Antwerp without many constraints and limitations compared to installing eight MMTs in the port area. All the more so since eight MMTs are not profitable. The same analogy can be applied to the port of Rotterdam. In terms of the KPIs, insights from the analysis give detailed information about the estimated utilization rate of the MMTs, and the estimated volume of container cargo to be handled annually. This information is useful for detailed daily planning of labor, time slots in sea terminals, and daily handling operations.

Besides that, the economic evaluation revealed some cases where the MMTs are profitable. It does not necessarily mean that all the linked regions experience a positive net benefit but that the positive benefits exceed the negative ones. Table 5.6 below shows the details of the shippers' net benefits per region linked to the MMTs for the optimal case in both seaports. In the case of Antwerp, it is apparent that there are more regions with positive benefits than negative ones. Also, the positive figures are higher than the ones in the negative (except for NL31), resulting in a positive aggregated net benefit. In the case of Rotterdam, there are more regions with negative net benefits. But these can be compensated for by the fact that region NL41 has a positive net benefit and huge container volumes, resulting in overall positive net benefits after aggregation.

Nevertheless, not all regions experience a positive net benefit: that is why a redistribution mechanism of the overall benefit should be envisioned. So that even regions with an individual negative benefit can profit from the situation and are therefore incentivized to use the MMTs. Note that if the aggregate net benefit was to be negative, even the best redistribution mechanism would not be a sufficient incentive to use the MMTs. In this case, some subsidies should be provided to support the use of MMTs if it can be demonstrated that the use of MMTs will lead to some external cost reduction within the port area. This can be shown in the decrease in the number of vessels that can be achieved through MMTs rather than direct sailing to the terminals. Another yardstick could be reduced congestion levels in the port using the MMT.

Table 5.6: Details of shippers' benefit for regions linked with MMTs for both seaports, with the number of MMTs in parentheses

ROTTERDAM (4 MMTs)			
Linked region	**Benefit/TEU**	**Volume passing through MMTs**	**Number of months linked to MMTs**
DE13	16.80€	4,224	12
NL41	3.97€	259,597	12
NL42	3.87€	74,856	11
DE12	-1.25€	13,497	10
NL22	-5.94€	13,559	2
DEA2	-14.65€	4,631	1
FRF1	-15.36€	3,005	1
ANTWERP (2 MMTs)			
NL22	16.29€	21,977	12
BE24	13.03€	17,849	12
DE11	8.58€	11,735	12
DEB2	8.28€	8,453	10
DE71	8.15€	13,781	12
DE13	1.00€	3,602	5
BE23	-0.86€	36,738	12
BE22	-1.09€	25,488	12
NL31	-18.13€	27,805	12

Source: Nicolet et al., (2023)

Finally, this analysis shows that vessels with low payloads should be targeted for a business case and that some regions are more favorable than others. In particular, the economic evaluation shows that it is always profitable for vessels transporting less than 60 TEUs to call at MMTs. These findings are also supported by the barge operators' and shippers' viewpoints, where the KPIs inform when to use the MMTs. In addition, MMTs could also be envisioned for vessels that could offload a part of their containers that need to go to different terminals (small call sizes) and directly call at the sea terminals with large volumes.

The economic assessment has identified some economic benefits for each main actor and under which conditions these benefits can be realized. However, the implementation of the MMTs goes beyond just the economic gains; some other practical challenges might hinder the implementation and integration of the system in the port system and affect the market of such systems. Based on this, some key practical issues need to be considered. Firstly, infrastructural limitations of ports, such as the port layout, might limit the maneuverability of the MMTs or the barges mooring along the MMTs. Secondly, safety concerns and personnel and equipment working conditions could limit the use of MMTs from the port policy viewpoint. Thirdly, the downtime of the MMTs might affect their efficiency and operations. This concept is indeed a complex solution. An equipment breakdown could lead to long downtime, which could affect the overall efficiency of its operation. Additionally, critical exogenous factors such as weather conditions could affect operations. Adverse weather, such as high winds, heavy rain, and extreme weather, could pose a risk to the stability of the MMTs and affect the safe operation of the cranes and the safety of the containers.

Furthermore, demurrage and detention issues could positively and negatively impact the implementation of the MMTs. The purpose of the MMT is to reduce the wait time of barges and, ultimately, cargoes in ports. Achieving this could have a positive spillover effect on container demurrage and detention in ports, as the waiting time of containers in ports could be reduced by using this system. On the other hand, the lack of proper planning of the MMT operations could cause lots of backlogs and container congestion, thereby leading to revenue loss for actors and, as a result, significantly impacting the operationalization of the MMTs. Based on this, demurrage and detention issues must be carefully considered within the overall MMT system.

Finally, there could be an issue with integrating this system with the other established port systems. Integrating a design into the port system is a complex procedure, and a breakdown of information with, for instance, a yard management system or container tracking system could lead to delays or errors in container handling. This threatens the overall operation of the system in the port. All these issues and more need to be examined before they can be implemented and integrated into the port system.

5.7 Model transferability

This section addresses the transferability of model results to other ports and regions. To transfer an economic assessment model from a seaport to an inland port and from one region to another, similarities between ports and regions must be considered to determine how a model can be generalized and applied to other cases. Based on this, the current section examines similarities that could be exploited to facilitate the generalization of the economic assessment model to other cases.

Firstly, the waterway connection must be considered for the model to be applied in other regions/cases. Ports in which the model is to be used have to be located along major waterways where it can attract cargo from different regions within the waterway corridor. This is important in the model to identify whether or not a specific region would be better off directly using the port terminal or the mobile terminal.

Secondly, ports that can use this model need to be significant for their regional and national economies in such a way that they serve as an essential transportation hub for container transport. This is essential in the model, where the ports attract a high annual cargo volume from different hinterland regions. This leads to a high waiting time for container barges and the need for a dedicated barge space solution. Without a high volume, there would be no high waiting time for barges and no need to have a dedicated barge space solution.

Finally, the model requires the port to be able to attract international trade. Ports, where this can be utilized, must have strategic locations for international trade and play a critical role in connecting countries and regions and facilitating global trade. This way, there would be traffic of deep-sea vessels in the port, affecting the priority of container barges, thus the need for a dedicated barge space solution.

In general, the transferability of the model to other cases requires that the case have a major inland waterway connection to other regions, have some economic significance in attracting cargo, and is a main hub for international trade to be able to attract deep-sea vessels.

5.8 Synopsis

This study has demonstrated the economic potential of using the MMT as a solution for floating consolidation and dedicated handling space for container barges. An economic assessment methodology has been proposed for this purpose. In doing this, the proposed methodology combines logistics and economic aspects in a unified framework. It then provides insights into the MMT design, potential time and cost savings, operational constraints, and the market that can be targeted.

The proposed assessment methodology is applied to two ports (Rotterdam and Antwerp) and two cases (moderate seasonality and high seasonality scenarios). The overall conclusion of the analysis suggests that the MMTs are most suitable for regions and vessels with small cargo volumes and can deal with the effects of a high seasonality pattern (caused, for example, by a disruption). Regarding the specific ports, the study indicates that four MMTs would be optimal for the port of Rotterdam, while two MMTs would optimally be installed in Antwerp. Thus from the assumptions and available data, the concept can be seen as a viable solution from an economic viewpoint for consolidating and handling low container volumes.

The assumptions in the study have been reasonably used to represent practical situations. However, more detailed research should be conducted based on more data to generate a more accurate result for practical implementation. In particular, in this work, regional flows are used. Still, a study at the vessel level could provide more information, as the MMT operations could be simulated with a higher level of detail. For example, a queueing model could be introduced to accurately infer the vessels' waiting times at the MMTs and sea terminals. The shuttles and sea terminals could also be explicitly modeled; thus, every shuttle could be assigned to a specific sea terminal. Another consideration to be examined is the party investing and operating the MMTs. This factor needs to be examined in detail as this would have a significant impact on the level of relationship between the MMTs and the sea terminals. This would decide the practical operations of the shuttle barges to the sea terminals and whether they get fixed slots and no waiting time at the sea terminals.

Regarding the demand, an uneven split of containers between the sea terminals should be considered as it would be more realistic, and the different inland waterway vessel types could also be represented. This would help get a clearer idea of the market to target. Nevertheless, the present study is essential as it provides primary answers and makes the first step toward more detailed models.

Chapter 6 - Urban freight distribution: methodological framework of small innovative vessels for urban freight delivery

6.1 Introduction

Having analyzed port-hinterland transport in previous chapters, this section (Figure 6.1) researches how the cargoes can reach the final consumers sustainably and efficiently. Often, these cargoes must be broken down into smaller units at the distribution warehouses and transported frequently to the end users primarily concentrated in urban areas. Hence, the main characteristic of this type of activity is the frequent transport of small volumes to urban areas. This characteristic has different societal challenges, such as congestion, emission, pollution, accidents, and infrastructural degradation.

Figure 6.1: Urban freight transport

To address this, sustainable and efficient solutions must be examined to serve as an excellent alternative to the traditional transport mode (road transport) to urban areas. In light of this, the current chapter discusses the methodological framework for urban freight distribution using small inland waterways.

Transportation of goods is an essential component in enhancing economic development. Thus, it is no surprise that many goods are transported daily to urban areas. Small volumes primarily characterize these goods at frequent intervals, mostly delivered to small retail shops in cities. This complex delivery system has limited the scope of other transport modes besides road transport (Behrends, 2012).

De Langhe (2019) shared this concern and identified that there had been high vehicle movements by vans and lorries in recent years. This has resulted in environmental, social, and economic issues such as pollution, congestion, noise, increased private and public costs, infrastructural damage, and climate change. With these issues and several others, it has become necessary to explore the possibilities of using alternative modes of transportation such as rail, tram, and inland waterway transport to distribute the complex delivery of goods to city retail shops. This research will focus on urban areas with small waterway connections. This is so because, based on the different issues already identified in chapter one with the delivery of goods in urban areas, there is an urgent need to rethink how urban freight distribution should be carried out.

According to Quak (2008), the success of urban freight distribution rests on the balance of three significant factors: logistics, technology, and policies. Thus, examining the successful implementation of these factors is crucial to consider the possibility of using other transport modes for urban freight activities to reduce the pressure on freight flows by road. One way to go about this is to explore an alternative method of transport for last-mile delivery to shops and stores within the city; thus, it becomes necessary to examine the feasibility of urban freight distribution via small inland waterways in a commercial capacity in this research. Section 2.3.2 already established that using small waterways for urban transport is not a new concept. This means of transport was used in different city pilot projects. However, this transport mode's economic and commercial viability is yet to be quantified, especially from the social perspective. Furthermore, most pilot projects used conventional CEMT I/II vessels, often called Palletized Shuttle Barges (PSBs), for transport operations. This could affect the commercial possibility of this transport mode due to the shortage of captains and crew members.

This research thus adds value by taking an additional step in providing an option of using level 3 autonomous technology on board the vessel (more about the different levels of automation can be found in chapter two). With this, the vessel can navigate autonomously without human interaction. The captain, however, will be stationed remotely at the shore control center to take over as a fallback measure when there is a system failure. With this, the captain can monitor multiple vessels without being on-site. This significantly reduces the number and cost needed for commercializing this transport mode. In light of this, RQ 3 was identified. This research question examines the feasibility of shuttle barges for urban freight distribution from an economic and welfare viewpoint. To answer this question, a social cost-benefit analysis is conducted to examine the financial, investment, economic and social feasibility of the small waterway transport compared to the conventional transport mode. Based on this, the current chapter discusses the methodological framework for assessing the feasibility of small confined waterways for urban freight transport.

6.2 Methodological Framework

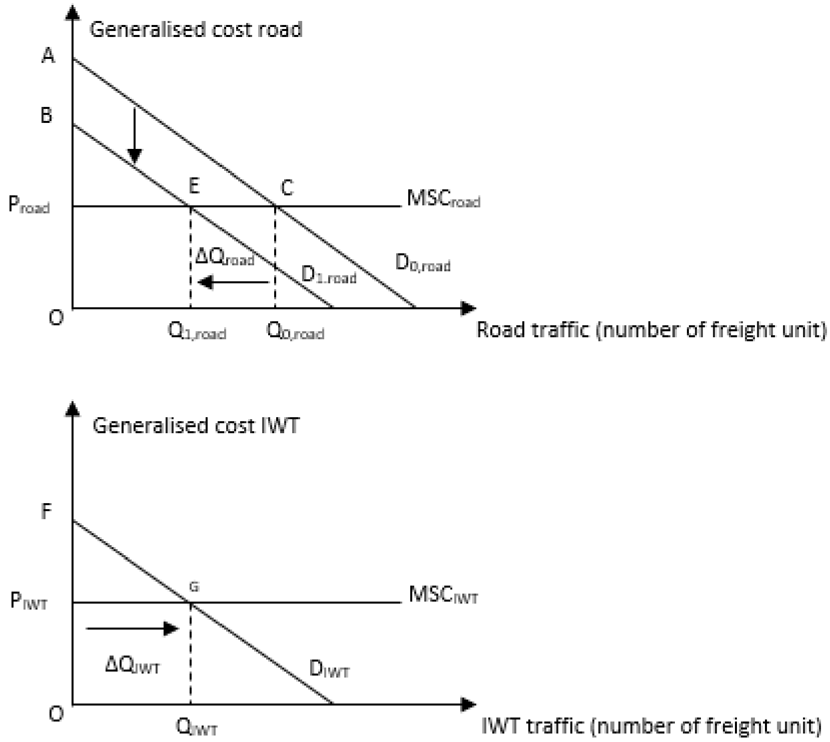
The use of small autonomous PSBs for urban freight delivery is a concept that could have an overall benefit for society; hence it is necessary to conduct an economic assessment of the feasibility of this solution from an urban perspective. An appropriate economic analysis technique for this type of solution is the social cost-benefit analysis (SCBA) method. This analysis examines the net benefit of each actor identified and provides an appropriate framework for developing an urban transport IWT model. In light of this, the social cost-benefit analysis shall be further discussed in the following subsections.

6.2.1 Social cost-benefit analysis (SCBA)

The fundamentals of SCBA can be traced to Blauwens (1988). They defined CBA as an analysis considering investments' advantageous and disadvantageous effects for all parties (states, interest groups, and organizations within the project framework). Van Wee and Tavassy (2008) further explained the concept of SCBA, including an overview of a project's pros and cons. The evolution of SCBA has evolved from the framework where only direct impacts were considered to an approach where direct, indirect, and external effects are considered for all stakeholders. A theoretical representation of the SCBA is discussed in line with this new approach.

Introducing PSBs for last-mile urban freight distribution creates a sub-market for a modal shift from road to IWT traffic within the total urban freight traffic. The social effect of this shift is illustrated in Figure 6.2. The first diagram reveals the change in the sub-market for urban road freight traffic. The second part of the figure shows the change in the sub-market for urban IWT freight traffic. As seen in the first diagram, there are two demand curves for road freight; the initial demand curve before the introduction of the urban IWT freight solution ($D_{0,\ road}$) and the demand curve after introducing the urban IWT freight solution ($D_{1, road}$). From the diagram, the possibility of a new transport option for urban freight (IWT) creates a downward shift in the demand curve of urban freight road transport from $D_{0, road}$ to $D_{1, road}$. The downward shift in the demand curve of road transport eventually reduces urban freight road traffic from $Q_{0, road}$ to $Q_{1, road}$ (ΔQ_{road}).

Figure 6.2: Change in urban freight road and IWT traffic



Source: Own creation

The second part of the figure reveals the demand curve and marginal social cost of the freight transport option ($D_{IWT,}$ and $MSC_{IWT,}$ respectively). From the diagram, IWT freight traffic increases from 0 to QIWT (represented by ΔQIWT) after introducing the urban IWT transport option. This increase is due to the partial shift from road traffic (ΔQ_{road}) to IWT traffic.

Having explained the graph, the social costs and benefits attached to the introduction of urban freight IWT solution can then be derived. The costs can be found in area MSC_{IWT}, while the benefits are in area $FGQ_{IWT}O$ (total revenue). Subtracting the costs from the benefits leads to a gain in net benefits of IWT represented in area FGP_{IWT}. Comparing the two diagrams in Figure 6.2, the benefits of introducing an urban IWT freight transport solution can be derived. This is derived by subtracting the area ACEB (loss in net benefits of road transport due to a shift from road to IWT) from FGP_{IWT} (gain in net benefits of IWT). Each actor's benefits can be determined when the urban freight IWT solution's total benefits are known.

Based on this, the perspectives of cost-benefit can then be established. Cost-benefit can be viewed from two perspectives; the industrial economics perspective and the welfare economics perspective.

The Industrial-economics perspective measures the project's benefits from the viewpoint of the private actors (De Langhe, 2019). This perspective is represented as:

$$\Delta R_p - \Delta C_p \qquad \textit{Equation 23}$$

Where;

ΔR_p = Change in private revenues.

ΔC_p = Change in private cost.

On the other hand, the welfare-economics perspective measures a project's benefits from society's viewpoint. It is estimated as follows;

$$\Delta B_s - \Delta C_s \qquad \textit{Equation 24}$$

Where;

ΔB_s = Change in benefits for society.

ΔC_s = Change in costs for society.

The combination of these two cost-benefit perspectives is known as social cost-benefit analysis (SCBA). SCBA monetizes all costs and benefits attached to a project from the social point of view. It is an analytical tool to appraise investment decisions to determine the welfare change attributed to a project. SCBA goes beyond the corporate return on investments; it captures overall societal benefits. As a general rule, the success of a new project from the SCBA is represented as:

$$\begin{pmatrix} \Delta R_p - \Delta C_p > 0 \\ \Delta B_s - \Delta C_s > 0 \end{pmatrix} \qquad \textit{Equation 25}$$

This equation implies that the private and social net benefits must be positive; otherwise, there is no incentive to continue the project. For projects with a negative net benefit to be successful, there must be considerable compensation to make the net benefit (both private and social) positive. This compensation can be in the form of subsidies. The introduction of support could lead to several situations.

The first situation is the best-case scenario with net benefits for private actors and society. In this case, the project will most likely be implemented. The second situation is a net loss for private actors but a positive net benefit for society. In this case, it is possible to execute the project by subsidizing private actors to ensure they have positive net benefits. The third situation is a positive net benefit for private actors but a net loss for society. In this case, there is no incentive to implement the project from the societal point of view unless there is a sort of compensation that would benefit society, which is to be provided by private actors. The last situation is the worst-case scenario with negative net benefits from private actors and society. The project, in this case, is improbable to be implemented because there are no incentives from both perspectives to implement the project.

Having identified the net benefit/loss situations for the actors, the implementation path can then be specified. The flow chart in Figure 6.3 displays the pathway to new project implementation's success/viability or failure. This research will focus on private actors' cost and benefit performance (industrial economics) and society (welfare economics). Potential barriers and oppositions to project implementation success are beyond the scope of this study. Based on this, it becomes necessary to identify the SCBA steps as they form the basis for developing a social cost-benefit transport model for PSBs. Based on this, the steps of the SCBA model are specified in the following section.

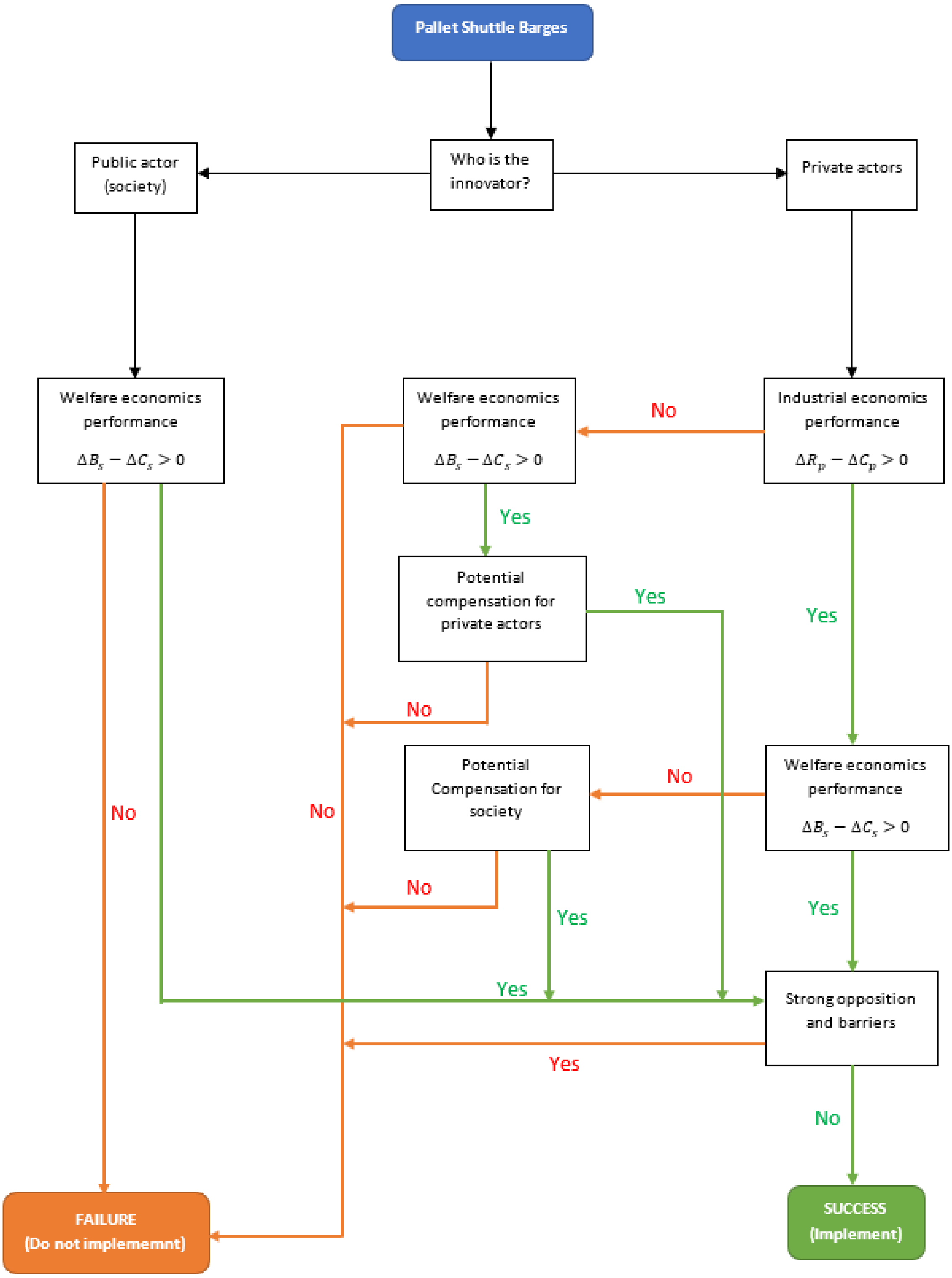
6.2.2 Steps in the SCBA method

Some steps must be followed in calculating the potential net benefit of the autonomous PSBs for last-mile urban freight distribution. According to De Langhe (2019), there are eight steps to calculating SCBA. However, in the scope of this research, seven steps will be adopted for this study. The seven steps are listed below and discussed in the following subsections.

1. Specifying the reference case and the set of project cases.
2. Identifying the different actors that are impacted by the project cases.
3. Identifying the potential impact and decision criteria for each actor.
4. Quantifying and monetizing all impacts.
5. Appraising the project and evaluating each actor.
6. Dealing with uncertainty and risk (scenarios and sensitivity).
7. Making recommendations based on the outcome of the analyses.

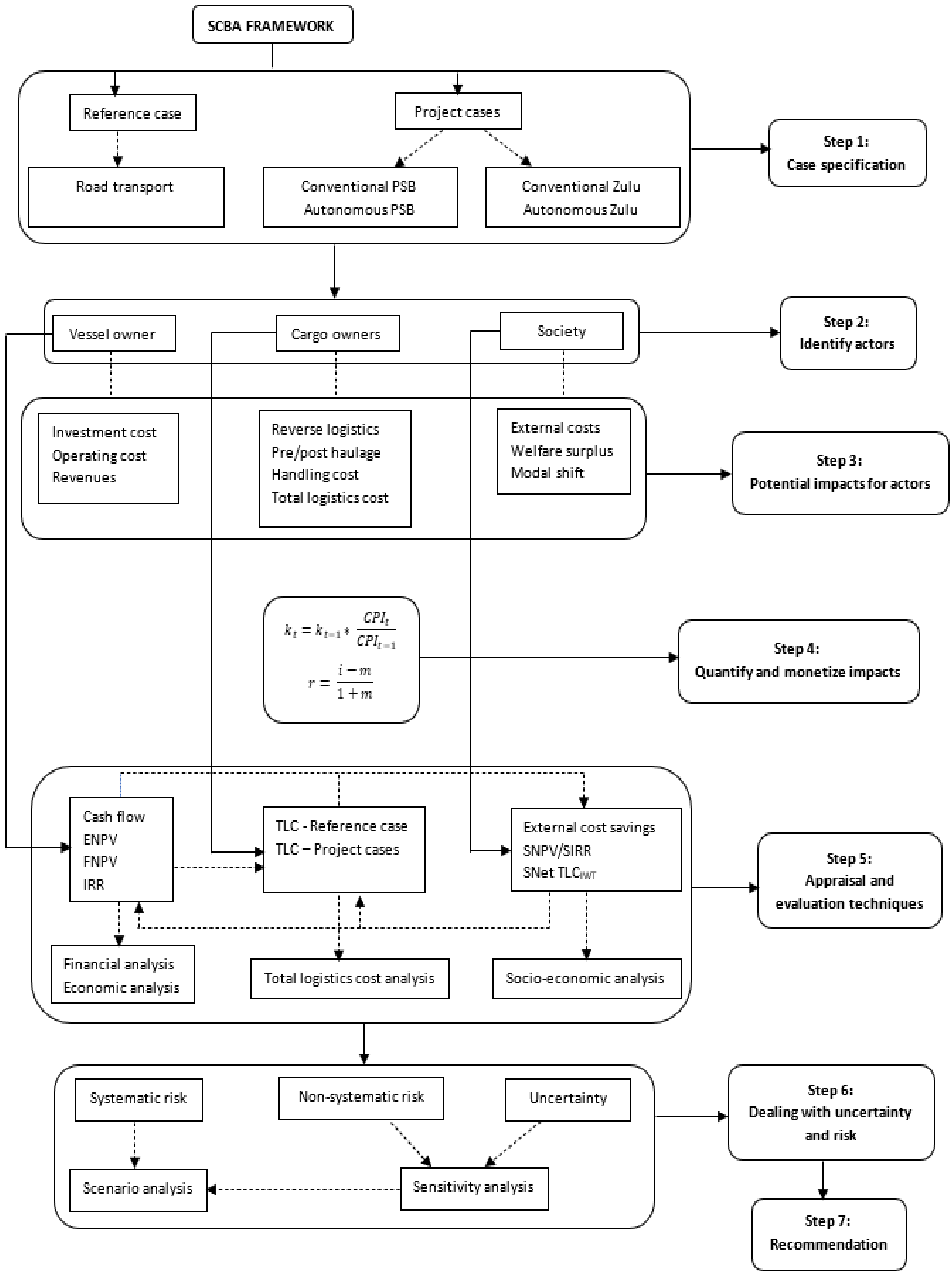
The above steps are presented in a schematic diagram in Figure 6.4, showing how they interact and are linked. The interactions displayed in the figure are further explained in detail.

Figure 6.3: Autonomous PSBs implementation pathway



Source: Own creation based on Aronietis (2013)

Figure 6.4: Schematic diagram of SCBA steps



6.2.2.1 Step 1: Specifying the reference case and project case

In developing an SCBA model, the reference case and alternative project cases must be determined. The reference case implies the current transport option for distributing goods to the urban area. This current transport option is the use of road transport. On the other hand, alternative project cases are the innovative solutions available within IWT transport for urban freight distribution. This research identifies two solutions: PSB for urban freight distribution and Zulu vessels for urban freight distribution. The reason for these two solutions is to understand whether the size and capacity of the vessels could contribute to the operational and economic viability of the transport option. These two solutions are further broken down into two sub-cases: conventional autonomous PSBs and conventional and Zulus. This is to determine whether the investments in autonomous technology would enhance the net benefits for the different actors. The different cases and sub-cases are presented in Table 6.1

Table 6.1: Developed cases

Case	Transport mode	Characteristics	Payload
Reference case	Trucks	Conventional	≤ 16 T
Project cases	PSB	Conventional	20 T
		Autonomous	20 T
	Zulu	Conventional	69 T
		Autonomous	69 T

Based on this, the actors and their respective interests are discussed in the next step.

6.2.2.2 Step 2: Identifying the different actors impacted on by the project cases

Different actors are involved in urban freight distribution (UFD) activities, and these actors have different interactions and interests in their involvement in the UFD process. Regué & Bristow (2013) noted that the different costs and benefits within an urban freight framework, in one way or another other, impact each actor in the UFD activities. Hence, it is crucial to identify the main actors in this system and the potential costs and benefits of each actor. Afterward, detailed analyses can be conducted on how each actor is affected.

In identifying the main actors, Taniguchi (2008) classified the actors into four groups; shippers, Logistics service providers (LSPs), Consumers/residents, and City planners/municipalities/prefectures/national government. Quak (2008) categorized these actors into three groups three: the government, professionals, and the impacted, while Wolpert & Reuter (2012), in their research, categorized them into five groups; carriers, public authorities, receivers, residents, and shippers. In the study of Cleophas et al. (2018), the actors were categorized into businesses, citizens, logistics service providers, and the public sector, while De Langhe (2019) identified shippers and receivers, logistics operators, impactees and public actors as the main actors in UFD.

From all these classifications, it can be concluded that there are three main actors in UFD: the transport owners, the cargo owners, and society. The transport owners comprise the transport provider, operator, and logistics companies. Cargo owners include the supplier/shipper and the receiver/customer. Society, meanwhile, consists of the authority and inhabitants of the society. Thus, the actors shall be classified as vessel owners, cargo owners, and society in the context of this study. These actors have different roles in UFD activities; their respective roles are specified in Table 6.2.

Table 6.2: Urban freight distribution stakeholders and roles

Actor	Type	Roles
Vessel owner	Private	• Offers transport services for different modes • Offers logistics services • Owns and operates barges, trucks, and vans
Cargo owners	Private	• Supplies goods from the origin • Pays for transport and logistics cost • Receives goods at the destination • Sells goods to consumers in an urban area
Society	Public	• Works in an urban area • Lives in or visit the urban area • Makes use of urban infrastructures • Provides and manages infrastructures • Provides maintenance service • Makes regulations on infrastructural use and access in urban areas.

Source: Own composition based on (Behrends, 2012; Dablanc, 2007; De Langhe, 2019; Quak, 2008)

In terms of their preferences with UFD, Maes (2017) noted that the actors have varying preferences based on the utility criteria they aim to derive in urban freight distribution. The preferences and utility criteria of each actor are specified in Table 6.3.

Table 6.3:Stakeholder urban freight distribution preferences

Actor	Preferences	Utility Criteria
Vessel owner	Reliable service delivery	Ensuring customer satisfaction
	Profit maximization	Enhancing profitable operations
	Viable return on investment	Achieving a positive return on investment
	Employee satisfaction	Ensuring a conducive working environment for employees
	Connectivity and accessibility	Utilizing good and accessible transport infrastructure
Cargo owners	Goods safety	Ensuring the safe delivery of goods
	Reliable and regular service	Utilizing Available and accessible transport service
	Efficient logistics service	Achieving reduced logistics costs and optimized service
	Convenient delivery location	Ensuring proximity to the receiver
	Transport cost	Achieving reduced transport cost of goods
Society	Positive business environment	Attracting new business opportunities
	Green concerns	Reducing CO_2, NO_x, $PM_{2.5}$, and PM_{10}.
	Regulatory framework	Making policies that make the environment conducive to live
	Accessibility	Reducing congestion and making transport accessible
	Quality of life	Reducing accidents, sickness, and environmental impact

Own composition based on Maes (2017)

As seen in Table 6.3, each actor's preferences and utilities within UFD activities differ. For instance, while the utility criteria of the vessel owner are primarily on profitability and high return on investment, the utility criteria for cargo owners solely focus on low transport and logistic cost. Meanwhile, those of society include reducing environmental impact and improving the overall quality of life. In the context of these different preferences, this research examines how the net benefit of each actor is affected by comparing the base case to the solution cases. This is done from a logistic, economic, financial, and societal viewpoint. However, the potential costs and benefits must first be identified. In their research, De Langhe (2019) and Verberght (2019) provided a non-exhaustive list of possible costs and benefits for the different actors. This list is summarized in Table 6.4.

Table 6.4: Non-exhaustive list of possible costs and benefits for different actors

Actor		**Costs**	**Benefits**
Vessel owner	Investment cost	Technology, R&D cost Capital cost Interest cost	Minimizing operating cost Optimizing operations Gaining market share Achieving business growth Enhancing competitive advantage Achieving a positive return on investment
	Financial cost	Repair and maintenance Personnel Administration Insurance Energy	
Cargo owners	Logistics cost	Transport cost Handling cost Rent and storage cost Waiting cost	Reducing transport cost Accessibility and efficiency Enhancing logistics performance Achieving a shorter lead time
Society	External cost	Emission Greenhouse gasses Congestion Infrastructure Accidents Noise	Reduced air and noise pollution Less congestion on the roads Fewer accidents Less greenhouse gas emissions

Source: Own composition based on De Langhe (2019) and Verberght (2019)

Based on this, the next step is identifying the potential impact and measurement indicators. This is discussed in the following subsection.

6.2.2.3 Step 3: Identify the potential impact and decision criteria for each actor.

In examining the potential of the identified options, the impacts that would lead to a change in costs and benefits from the private and welfare viewpoints must be identified for the different actors. Starting with the vessel owner, the costs include investment and technological costs, operational costs, loan repayment, and loan interest. Meanwhile, benefits mainly include the revenues that will be derived and the potential external savings.

The investment costs comprise the initial investment of the vessel and the residual value after the life span of the barge. The initial investment is determined by summing all financing sources such as public contributions, loans, private equity, and all interests accrued to the financing sources. In contrast, the residual scrap value is determined by calculating the net present value of the cash flows in the remaining economic life of the vessel.

The technological costs especially for the autonomous solution, also need to be specified. These costs include using a control unit, communication, remote control, vessel positioning, camera installation, sensor installation, and data computation. The technological costs can be distinguished into two; fixed technical costs and variable technological costs. The fixed technological costs are included in the general investment costs. In contrast, the variable technological costs are included in the general operational costs in the cash flow statement of the vessel owner.

The operating costs include all costs related to the operation and maintenance of the transportation service. It also consists of the marketing and insurance services of the vessel. Revenues, meanwhile, are mainly the amount paid by the shippers for using the transport option and the possible subsidies that could also be received if the private benefit is low or negative.

Financial and economic analyses are carried out to determine the vessel owners' net benefit. According to De Langhe (2019), financial analysis measures the return on capital of a project, while economic analysis measures the project's return on investment. The cash inflows and outflows covering a specific time horizon are used in these analyses. The time horizon represents the economic life of the investment. Real prices and the real discount rate are used to calculate the cash flows for the identified time horizon of the project.

To calculate the return on capital for the financial analysis, operational costs, technological costs, infrastructure costs, public contribution, private equity, repayment of loans, and accrued interests are subtracted from the revenues and residual value of the project. For the economic analysis, however, the investment costs are deducted from the net income to ascertain how much the project's net cash flow compensates for the amount invested. A general rule for this type of analysis is that the internal rate of return must be greater than the discount rate; otherwise, the revenues generated will not be enough to cover the costs.

For the second actor, the cargo owners, total logistics costs (TLC) are calculated. This calculation compares the solution cases' TLC to the current transport option (road transport) TLC. A lower TLC would benefit the cargo owners, while an increased TLC would lead to additional costs. The elements of the TLC determined for cargo owners include; transportation costs, handling costs, cost of waiting time, rent costs, cost of the cycle, cost of inventory, and cost of safety cost. These different costs are further elaborated on in subsequent subsections.

Finally, for society, social cost-benefit analysis is carried out to examine the impact on society. This analysis calculates the different external costs, and the external cost savings are derived. The external cost savings are added to the investment to derive the project's societal impact for all parties involved.

Having identified the different possible cost-benefit impacts for the actors, the possible outcomes and decision criteria must be determined. A combination of net benefits can be achieved regarding the potential results. Based on these combinations, the decision criteria for the project can be specified. Table 6.5 provides an overview of the possible outcomes and the decision criteria for each combined outcome.

Table 6.5: Possible outcomes and decision criteria

Actor	Possible outcomes					
Vessel owner benefit	> 0	< 0	> 0	< 0	> 0	< 0
Cargo owners benefit	> 0	< 0	< 0	< 0	> 0	> 0
Society benefits	> 0	< 0	> 0	> 0	< 0	> 0
			Decision criteria			
Project evaluation	Positive Implement project	Negative Stop project	Positive if cargo owners can be compensated for; **otherwise, negative.**	Positive if the vessel owner and cargo owners can be compensated; **otherwise, negative**	Positive if society can be compensated for; **otherwise, negative.**	Possible if the vessel owner can be compensated; **otherwise, negative**

Source: Based on van Hassel et al. (2018)

As seen in Table 6.5, there are five possible outcomes for the benefit of the actors. The first outcome is the best-case scenario where all actors have positive net benefits. In this case, the solution is said to be positive and can be implemented. The second outcome is the worst-case scenario where all actors have negative net benefits. In this case, the solution is said to have a negative impact, and there is no incentive to implement it. The other four possible outcomes combine negative and positive net benefits for at least one of the actors. In these situations, the project can be positive if the actor with a negative net benefit is duly compensated; otherwise, the project would have a negative impact.

The measurement indicator must be determined by identifying possible outcomes and decision criteria. In doing this, the monetary value of all costs and benefits are represented in Euro_{2020}. Furthermore, logistics analyses of the goods are calculated per euro pallet. The rationale is that most goods transported via trucks are mainly palletized cargo which, according to Mommens, Lestiboudois, & Macharis (2015), have about 23% share of the loading unit for all freight transport in Belgium. This resulted in over 67 million tonnes of yearly palletized goods on Belgian roads in terms of volume. Moreso, the vessels being investigated are suitable for mostly palletized cargoes. The cost-benefit values are quantified and monetized in the following step.

6.2.2.4 Step 4: Quantify and monetize all impacts.

In this step, possible impacts are quantified and monetized. The monetary values are in Euro_{2020} values, as earlier stated. Using the consumer price index (CPI), all values generated from literature and secondary sources are converted from the base year to the current year (2020) using the consumer price index (CPI). This index, according to Rebel (2013), is represented as follows:

$$k_t = k_{t-1} * \frac{CPI_t}{CPI_{t-1}}$$ *Equation 26*

Where;

$t-1$ = Base year

t = Current year

k_{t-1} = Value of figure in the base year

k_t = Value of figure in the current SCBA year (2020)

CPI_{t-1} = Consumer price index in the base year

CPI_t = Consumer price index in the current year

All CPI values are generated from STATBEL[12]

The time horizon of the project needs to be defined to obtain the present value of the project over the entire life span. This notion was argued by Blauwens et al. (2016), who noted that the discounting period of a project should be equal to the lifespan of the project effect. Sequel to this, different studies have proposed a general time horizon for an SCBA. For instance, Gwee et al. (2008) specified that an SCBA project should have a time horizon of between 20 and 30 years. For inland navigation, Verberght (2019) uses a lifespan of 40 years for the SCBA of conventional and autonomous vessels based on the European cost-benefit handbook for IWT. Meanwhile, Kretschmann, Burmeister, & Jahn (2017) specified an operational lifespan of 25 years for autonomous and conventional bulk carriers based on the demolition age in the bulk market. All these are, however, based on large inland vessels. For smaller vessels like the PSBs, a smaller life span of 15 years is used for the cost calculation in this study, with a rate of 1.4% (NBB[13] 2020).

All values related to the costs and benefits of the different stakeholders over the project's lifetime are converted to the year 2020 values. In doing this, an appropriate discount rate must be determined for the cost and benefit calculations of the different stakeholders. There is no consensus on the proper discount rate when evaluating a project. For instance, Kretschmann et al. (2017) use a discount rate of 8% in their study, while Verberght (2019) uses a discount rate of 10% in his analysis, and De Langhe (2019) adopts a real discount rate of 4% in her analysis.

The KCE report by Cleemput, Neyt, Van De Sande, & Thiry (2015) recommended a 3% discount rate for future costs and benefits of a project. According to them, this is due to other countries' base case economic guidelines. However, they suggested conducting sensitivity with a discount rate between

[12] statistics of Belgium in figures

[13] National Bank of Belgium

0% and 5% for both the costs and benefits. In line with this, the current research will adopt a discount rate of 6% for this study.

6.2.2.5 Project appraisal and evaluation technique for actors.

The project appraisal techniques are divided into three, one for each actor. The Net Present Value (NPV) and Internal Rate of Return (IRR) technique are calculated for the vessel owner. This is derived from the estimated free cash flow for the investment. The cargo owners use the total logistic cost (TLC) approach to evaluate the project's impact. Meanwhile, external cost calculations assess the project's benefit to society. These evaluation techniques are further elaborated on and modeled below:

6.2.2.5.1 Project evaluation model for vessel owners

The free cash flow must be calculated to determine the vessel owner's net benefit. The free cash flow is based on the revenue and cost components of the investment. The steps in calculating the free cash flow are shown in Table 6.6 based on van Hassel's (2011) and De Langhe's (2019) specifications.

Table 6.6: Free cash flow calculation of vessel owner

Step	Items	Calculation
1	Revenues	Operational income
2	Operational cost	Voyage + maintenance + labor + variable technological cost
3	Overhead cost	Insurance + legal fees
4	EBITDA	1 – (2 + 3)
5	Depreciation	Capital and fixed technological investments/project lifespan
6	Operational result	4 – 5
7	Interest	Loan * interest on the loan
8	EBT	6 – 7
9	Tax	If 8 <= 0, 0; otherwise 8 * tax rate
10	EAT	8 – 9
11	Cash flow	10 + 5
12	Payback loan	Loan/payback period
13	Free cash flow	11 – 12
14	Discounted free cash flow (PV)	13/(1+discount rate)^time period

Source: Own composition based on van Hassel (2011) and De Langhe (2019).

$$PV = \sum_{t=0}^{T} \frac{free\ cash\ flow}{(1+r)^t}$$ *Equation 27*

Where;

t = Time horizon expressed in years after the base year analysis

r = Annual discount rate

PV = Discounted free cash flow

T = Time horizon of the investment (15 years)

Calculating free cash flow and discounted free cash flow follows the research of van Hassel (2011) and De Langhe (2019) research. As seen in the table, the first step is to derive the total operating income for the vessel owner. This income includes all revenues from operating the vessel and transporting goods from one location to another. Step two determines the total cost of operating the vessel, such as the voyage, maintenance, and technological costs. The voyage cost includes fuel, crew cost (in the case of a conventional vessel), maintenance cost, labor cost, and the variable technological costs (in the case of an autonomous vessel) earlier identified. Next is calculating the overhead cost, including insurance, legal fee, and marketing cost. After this, the earnings before interest, tax, depreciation, and amortization (EBITDA) is calculated by subtracting the operational and overhead costs from the operating revenue.

In step 5, the depreciation is calculated by dividing the capital and fixed technological investments (in the case of an autonomous vessel) invested over the project's life span. This result is subtracted from EBITDA to give the operational effect in step 6. Step 7 calculates the interest payable per year by multiplying the loan by the interest on the loan. The result is subtracted from the operational result to give earnings before tax in step 8 (EBT). In step 9, the payable tax is calculated. Tax can only be calculated if the EBT is greater than 0; otherwise, no tax is charged on the investment. The deductible tax is derived by multiplying the EBT by the specified company tax rate in the country. This leads to step 10, the earnings after taxes (EAT).

Step 11 calculates the investment's cash flow by adding EAT (step 10) with depreciation (step 5). The payback loan for the project is then calculated in step 12 by dividing the initial loan by the payback period of the loan. This leads to step 13, where the free cash flow is obtained. This is derived by subtracting the payback loan (step 12) from the cash flow (step 11). The final step is to discount the free cash flow to the present value throughout the project's lifespan.

An appropriate appraisal method must be determined after calculating the vessel owner's free and discounted cash flow. Different appraisal methods exist in the literature, such as the net present value, internal rate of return, weighted average cost of capital, and benefit-cost ratio. However, the net present value (NPV) remains the most widely used appraisal technique to evaluate a project from these different methods. Other appraisal methods serve as additional techniques to support the decision of the NPV appraisal technique.

De Langhe (2019) recommends that the NPV appraisal technique for an investor (vessel owner) should be evaluated from economic and financial perspectives. The difference between these two perspectives is that while the financial perspective evaluates the return on capital of the project, the economic perspective evaluates the project's return on investment. In line with this recommendation, this research breaks down the NPV of the vessel owner into two. This is expressed in Equation 28 and Equation 29, respectively.

The first specified equation is the economic net present value (ENPV). As seen, ENPV measures the project's return on investment. This is derived by subtracting the change in investment costs and operating costs per year from the change in the project's revenue per year and dividing it by the discounting factor in the specified year. The other part of the equation shows the residual value of the vessel discounted to the present value. The discounted residual value generates some income for the vessel owner; thus, it is added to the first part to generate an ENPV value per year.

$$ENPV = \sum_{j=t_p-t_r}^{j=t_n-t_r} \frac{\Delta R_j - (\Delta I_j + \Delta C_j)}{(1+r)^j} + \frac{K_j}{(1+r)^j}$$ *Equation 28*

Where;

R_j = operational income in year *j* without external cost savings;

I_j = Investment and technological cost in year *j*;

C_j = Operating costs in year *j;*

r = Discount rate

K_j = Residual value in year *j*

From the ENPV, it is clear that the return on capital for the project is not included. The financial net present value (FNPV) must be calculated to obtain the return on capital. This equation is similar to the ENPV with adding the financial cost, subtracted alongside the investment and operational costs from the operating revenues and residual value.

$$FNPV = \sum_{j=t_p-t_r}^{j=t_n-t_r} \frac{\Delta R_j - (\Delta I_j + \Delta C_j + \Delta F_j)}{(1+r)^j} + \frac{K_j}{(1+r)^j}$$ *Equation 29*

Where;

F_j = Financial cost in year *j*

6.2.2.5.2 Project evaluation model for cargo owners

The appraisal technique for cargo owners is specified in this section. This is expressed in *Equation 30* as the total logistics cost (TLC). The TLC model in this research is adapted from Mommens et al., (2015) and Blauwens, Vandaele, Voorde, & Vernimmen, (2016).

$$TLC = TC + \left(\frac{1}{R} * \frac{Q}{2} * v * h\right) + \left(Lt * v * \frac{h}{365}\right) + \left(\frac{1}{R} * v * h * K * \sqrt{(Lt * d) + (D^2 * l)}\right)$$ *Equation 30*

Where;

R = Annual volume (TEU).

Q = Loading capacity (in units).

v = Value of goods (EUR/unit).

h = Holding cost [fraction of value/yr].

Lt = Average lead time [days].

K = Safety factor.

D = Average daily demand (units/day).

d = Variance of daily demand (units^2/day).

l = Variance of lead time (days^2).

The first part of the equation is the transport and handling costs, the second part focuses on the cycle stock, the third part emphasizes the inventory in transit cost, and the last part is the safety stock. This formula is used to calculate the TLC for the cargo owners in the private case. To estimate the TLC from the welfare perspective, the external costs are internalized for the cargo owners. This is achieved by adding external costs to the initial costs. The formula for the internalization of the external costs for the cargo owners is specified as follows:

$$\frac{E_{C.T} * v}{D} \qquad \textit{Equation 31}$$

Where;

$E_{C.T}$ =Total external costs (Eur/tkm)

v = Value of goods

D = Distance

6.2.2.5.3 Project evaluation model for society

The social net present value (SNPV) calculates the project's net benefits. Different external costs for the project and reference cases are calculated and compared. Transport activities lead to different environmental impacts such as congestion, accidents, climate change, and wear and tear of transport infrastructures. The costs of these different impacts are often borne by society but not accounted for by the transport users when they make transport decisions. These costs are known as external costs of transport.

According to the welfare theory, internalizing external costs could lead to more efficient transport infrastructure use and reduce transport activities' adverse effects while enhancing fairness among the transport modes and users. This subsection will focus on the external costs generated in implementing transport activities in line with this analogy. Specifically, this section will focus on the following costs; accident cost, air pollution cost, climate change cost, noise cost, congestion cost, well-to-tank (up-and downstream process) cost, and infrastructure cost.

External costs, also known as externalities, are a situation whereby the side effect of an activity imposes some costs to society that are not accounted for by the group carrying out the activity. In essence, transport activities generate some costs and benefits. However, while the transport users enjoy the benefits, the costs are generally not borne by the transport users but are passed on to society; thus, transport users do not consider these costs when making transport decisions.

By internalizing these costs, the effect of externalities forms part of the decision-making process of the transport users in their travel decision and mode of transport. Internalizing external costs can be carried out in two methods; either directly through regulations and control measures or indirectly through market-based instruments (such as taxes, emission trading, and charges). The focus of this research is on the second method of internalization (market-based instruments). This method is seen as an efficient way to limit the negative effect of transport while generating some income for the government. The method has enhanced the modal shift from road transport to other modes, especially in urban freight distribution. This method of internalization requires detailed and reliable estimates of external costs as it provides the main input parameters for cost-benefit analyses. To correctly specify and estimate the external costs, it is essential to distinguish between social costs and private costs.

Social costs are borne by society due to the provision and use of transport infrastructures. Examples include; the cost of infrastructure, accidents, congestion, environmental costs, and capital costs. Private costs, also known as internal costs, are directly borne by the transport user when partaking in transport activities. Examples include; wear and tear, own time cost, transport fare, fuel cost, transport charges, and taxes. The difference between these two costs is known as the external cost of transport. Different external costs are distinguished under three categories by van Essen et al. (2019). These are; total external costs, average external costs, and marginal costs.

Total external costs refer to the external costs within a geographical boundary. They are usually presented in billions or millions of Euros. Average external costs measure the total costs by the transport performance per mode. They express the costs per transport performance unit of vehicles. They are calculated by dividing the total costs by the total transport performance and are usually measured in €-cent/pkm, €-cent/tkm or €-cent/vkm[14]. Marginal external costs, meanwhile, refer to the additional costs of transport emanating from the additional transport activity. These costs are also measured in €-cent/pkm, €-cent/tkm and €-cent/vkm. According to Korzhenevych et al., (2014), marginal costs are the most appropriate external cost measurement. It serves as the basis for applying the market-based instrument to account for the societal impact of additional transport activities. Thus, the marginal cost values will be used in this study.

According to the European Environment Agency (2013), marginal external cost values depend on several factors, such as vehicle tonnage, engine type, driving patterns, number of axles, location, time of the day, and population density. The value of external costs for different transport modes and vehicle characteristics can be calculated based on these factors. However, it is crucial to identify external cost classifications before calculating them. External costs can be divided into seven main

[14] Pkm = Passenger kilometer, tkm = tonne kilometer, vkm = vehicle kilometer.

categories, which are; congestion, accident, air pollution, noise, climate change, infrastructure cost, and WTT[15] cost (Korzhenevych et al., 2014; Papoutsis, Dewulf, Vanelslander, & Nathanail, 2018; van Essen et al., 2019). These categories are specified as follows:

$$E_c = acc_{cost} + air_{cost} + CC_{cost} + noise_{cost} + cong_{cost} + WTT_{cost} + infra_{cost} \qquad \textit{Equation 32}$$

Where;

E_c = External costs

acc_{cost} = Accident costs

air_{cost} = Air pollution costs

CC_{cost} = Climate change costs

$noise_{cost}$= Noise costs

$cong_{cost}$ = Congestion costs

WTT_{cost}= Well-to-tank costs

$infra_{cost}$ = Infrastructure costs

The external costs for the different modes can be calculated and compared in line with these categories. Cost savings for the project cases (IWT) can be ascertained by comparing the external costs between the different modes. This is derived by subtracting the marginal external cost of IWT from the marginal external cost of road transport. The equation for this is represented as:

$$E_{c,savings} = E_{c,road} - E_{c,iwt} \qquad \textit{Equation 33}$$

The total external costs for each mode can be calculated as follows:

$$C_{tot,ext} = \sum_x (C_{ext} * D) \qquad \textit{Equation 34}$$

Where;

$C_{tot,ext}$ = Total external cost [EUR].

x = Specific transport mode.

[15] WTT = Well-to- tank emissions (also known as up- and downstream processes). These are emissions due to energy production of transport activities. They can also be referred to energy production costs.

$C_{ext,i}$ = external costs of the mode

D_i = Transport distance.

It is crucial to have appropriate and consistent marginal external cost data for a robust social cost-benefit framework. To ensure this, external cost data for Belgium were extracted and calculated from van Essen et al. (2020) dataset. Although the dataset provides values for the different external cost parameters, it does not present a complete overview of the externalities in IWT compared to road transport. IWT is generally considered to have low external costs. However, it still faces some external costs that have not been captured in the dataset. These costs include water pollution costs, biodiversity costs, the cost of modern and energy-efficient vessels, and safety costs. These costs could further increase the external costs of IWT but are not currently considered in the datasets.

Furthermore, some generated values within the dataset do not completely reflect the external costs on IWT. For instance, the basis of IWT accident cost calculation is questionable, as the data on the number of accidents on IWT are either unavailable or unreliable. Regardless of these weaknesses, this remains a popular reference source for external cost estimates. This is because it is one of the few sources that try to capture and monetize the major external cost elements in the three transport modes.

Values for Belgium were selected due to applying the external costs framework to a case study in Ghent. It is, however, possible to use the external cost values for other countries by adopting country-specific marginal external cost data for the different transport modes. As previously stated, marginal external cost values will be used for this study. Cost values are extracted from the handbook on external costs of transport developed by van Essen et al. (2019). All cost values have been discounted from the base year ($Euro_{2016}$) to the current year ($Euro_{2020}$) using the CPI index earlier stipulated. The next step is to assess each external cost and specify the cost/tkm for the transport mode. These external costs are explained in the following subsections.

Accident costs:

Transport accidents can occur in different forms, often leading to high costs for the parties involved. These costs could be divided into material costs (such as damages, administrative costs, and cost of treatment) and immaterial costs (such as pain, death, and productivity loss). While the material costs can be calculated using market prices, it is challenging to calculate immaterial costs. Therefore, it is essential to define the scope of external accident costs and specify the marginal social cost values for the transport modes and vehicle types in line with van Essen et al. (2019) Handbook.

According to the authors, external accident costs can be defined as the cost of transport accidents that are not covered by insurance premiums. This implies that an insurance system determines the internalization share of an accident; thus, costs not covered by insurance are regarded as external costs of an accident. The external accident cost components in van Essen et al.'s study are human costs, medical costs, administrative costs, production loss, and material damages. These categories are briefly explained below.

Human costs: These are pain and suffering due to transport accidents. These are immaterial costs and cannot be calculated using market prices. To estimate these costs, proxy values are used for the three classifications of human costs (slight injuries, severe injuries, and fatalities[16]). While injuries cover the pains and sufferings of the victim, fatalities cover the victim's loss of utility.

Medical costs: These are costs associated with the treatment of accident victims. These costs include hospital bills, rehabilitation centers, appliances, and medicines. It is assumed that part of these costs is already internalized; thus, van Essen et al. (2019) think that 50% of the medical expenses are external.

Administrative costs: are related to administrative duties in the event of an accident. This includes legal costs and deploying emergency services to the accident location. van Essen et al., (2019) assume 30% of these costs as external because most of the cost in this category has been internalized as a form of insurance.

Production loss costs: are associated with reduced working time and human capital development due to transport-related accidents. The researchers assume that 55% of gross production loss can be considered external costs.

Material damages: are direct market values of property (such as vehicles, freight, and personal belongings) and infrastructural damages resulting from transport-related accidents.

Air pollution costs

Air pollution often leads to different types of damage. According to van Essen et al., (2019), air pollution costs can be divided into four categories: health effects, crop losses, biodiversity loss, and material and building damages. These categories are explained briefly below:

Health effects include medical, production loss, and death costs due to inhaling air pollutant particles (PM10, PM2.5, and NOx), which increases the risk of respiratory and cardiovascular diseases such as asthma and bronchitis lung cancer.

Crop losses: These are damages to crops caused by the emission of NO_x, VOC, and SO_2. These damages often lead to lower crop yields.

Biodiversity loss: These are damages to the ecosystem caused by air pollution. Damages include acidification of soil and water and eutrophication of ecosystems. Emitting NOX, SO2, and NH3 cause these. The result of these damages is the reduction of biodiversities such as flora and fauna.

[16] Fatality is when a person dies immediately or within 30 days as a result of the injury sustained from an accident. Serious injury is the hospitalization of a victim for a period of more than 24 hours as a result of transport-related accidents. Slight injury meanwhile is any injury from transport-related accidents that does not fall under the definition of serious injury (UN, 2011).

Material and building damages: Air pollution leads to two main effects in material and building damage; corrosion of building surfaces caused by dust and particles and the deterioration of building facades caused by acidic substances such as SO_2 and NO_x.

Climate Change costs

Estimating the costs of transport activities on climate change is highly complicated due to the global and long-term effects of greenhouse gases which contribute to the risk patterns of climate change. However, it is essential to identify the climate costs of different modes of transport, specifically for Belgium. The definition and scope of climate change, in line with van Essen et al. (2019), are discussed. Climate change costs are all costs related to the effect of global warming. The results include rising sea levels, water management issues, biodiversity loss, extreme weather conditions, and crop losses. Climate change costs for transport are calculated based on the direct impact of CO_2, N_2O, and CH_4 emissions from transport activities.

Noise costs

Noise pollution from transport activities increases environmental problems due to urbanization and traffic volumes. Noise can be seen as unwanted sounds with varying intensity, duration, and quality, leading to physical and psychological harm to people (van Essen et al., 2019). Different noise threshold levels have been identified; however, van Essen et al. (2019) used a threshold of 50 dB(A)[17] for their external cost calculations. The reason for this is to avoid the underestimation of noise costs in their analyses. Frequent exposure to transport noise often leads to five main health problems, according to Defra (2014). These are stroke, heart disease, hypertension, annoyance, and dementia. The costs of these health effects have been included in calculating noise costs (van Essen et al., 2019).

Congestion costs

Congestion costs can be seen as the reduction in the speed and flow of other vehicles due to the introduction of an additional vehicle, leading to an increase in travel time and cost of transport. A distinction must be made between road congestion and congestion in other modes of transportation. While road congestion deals with the speed-flow relationship in a given context (such as urban, rural, or inter-urban context), congestion in other transport modes are determined by the allocative capacity of networks or nodes due to the scheduled services in which such modes operate. Thus, estimating the external congestion cost for road transport differs from how other modes estimate congestion costs.

While the congestion costs in road transport are estimated based on delay cost and deadweight loss, congestion in other modes of transportation is calculated based on the capacity of the transport mode. The cost of the mode capacity can be divided into two: scarcity cost and congestion cost. Scarcity is the opportunity cost to service providers for the non-availability of departure and arrival times. In

[17] dB(A): The basic measurement index for noise level with a frequency weight (A) which is used to correct for the sensitivity of human range of hearing, tones and intensity.

contrast, congestion cost is associated with the delay in a scheduled service caused by another planned service's late arrival or departure.

Costs of well-to-tank emissions

These are energy production costs related to transportation activities. These costs are also referred to as well-to-tank emission costs. They include the production (extraction, processing, and transmission) of energy sources for transportation, which causes emissions and externalities. It also comprises the energy plants and infrastructures involved during production, leading to toxic substances, air pollutants, greenhouse gases, land use, and environmental use. The costs included in this section include the costs of CO_2, CH_4, N_2O, $PM_{2.5}$, PM_{10}, NO_X, SO_2, and NMVOC related to the extraction, processing, transportation, and transmission of energy for transport activities.

Infrastructure costs

Transport infrastructure costs are direct expenses plus financing costs of infrastructures related to transport activities. They are equal to the sum of annual depreciation and financing costs in a particular year. In order words, infrastructure costs are the opportunity costs for not spending resources on more worthwhile causes. These costs are expressed as the interest in capital and include investments in new infrastructure, costs of renewal of existing infrastructure, operational expenditures, and expenditures on infrastructure maintenance.

Based on the explanation of the different identified externalities, their respective marginal cost elements can then be specified. The marginal external cost elements are extracted (adjusted to $Euro_{2020}$) from van Essen et al. (2019) and represented in Table 6.7.

Table 6.7: Marginal external costs for Belgium (€2020)

Element	**Mode**	**Cost (€-cent per tkm)**
Accident	Road	0.0023
	IWT	0.00057
Air pollution	Road	0.023
	IWT	0.012
Climate change	Road	0.0099
	IWT	0.0027
Noise	Road	0.0017
	IWT	0
Congestion	Road	0.0033
	IWT	0
Well-to-tank	Road	0.0041
	IWT	0.0014
Infrastructure	Road	0.0015
	IWT	0.0028

After specifying the different external cost values for reference and project cases, the costs can then be compared, and external cost savings can be derived. These savings serve as benefits to the vessel owner and are added as revenue to the free cash flow statement of the vessel owner. For cargo owners, external cost savings lead to reduced TLC reflected in the potential transport cost reduction. With a possible revenue increase for vessel owners, the societal appraisal of the project can be ascertained for the actors (vessel owner, cargo owners, and society) represented as:

$$Welfare\ NPV = \sum_{j=t_p-t_r}^{j=t_n-t_r} \frac{(\Delta R_j + \Delta E_{c,j}) - (\Delta I_j + \Delta C_j + \Delta F_j)}{(1+\mathrm{r})^j} + \frac{K_j}{(1+\mathrm{r})^j}$$

Equation 35

Where;

$\Delta E_{c,j}$ = Change in net external cost savings between the transport modes.

6.2.2.6 Step 6: Deal with uncertainty and risk (scenarios and sensitivity)

The next step after the appraisal technique is to deal with risks and uncertainties by performing sensitivity analysis and creating different scenarios. According to De Langhe (2019), there is a distinction between uncertainty and risk. The significant difference between these two concepts is that risks can be quantified based on probabilities, while uncertainties are project-related events that cannot be quantified.

Risks can further be divided into two types; systematic and non-systematic risk. Systematic risks relate to external environmental factors such as the macroeconomic environment, GDP growth, purchasing power, and price level. This type of risk is beyond the control of an individual and affects society as a whole. Different techniques can be adopted to mitigate this type of risk. Examples include; the Beta method, Monte Carlo simulation, Ramsey rule, and scenario analysis. The scenario method is adopted to minimize systematic risk in this project, whereby different cash flows are calculated based on potential macroeconomic scenarios. This is done using different discount rates between 0% and 8% for the NPV calculation. By doing this, the systematic risk is internalized for both the costs and benefits of the project.

Non-systematic risks, meanwhile, are risks that are directly related to the investment. They often stem from unreliable data, leading to underestimating costs and overestimating benefits. Examples include demand estimation, investment costs, project lifespan, etc. To mitigate this type of risk, sensitivity analyses should be carried out to identify the critical variables directly related to the project; afterward, scenario analysis is conducted for these variables.

In summary, critical variables related to unsystematic risk are determined by performing sensitivity analysis on all the variables associated with the project; afterward, scenario analysis is conducted alongside the systematic risk to assess the impact and ranks of the significant critical variables.

6.2.2.7 Step 7: Make recommendations based on the outcome of the analyses.

Based on the project appraisal techniques and the sensitivity and scenario analyses, the net cost/benefit is determined for the project, and the individual cost/benefit for each actor earlier identified is also defined. Good recommendations are made from the societal (welfare economics) analysis.

6.3 Synopsis

This chapter presents the methodological framework for analyzing the economic and commercial feasibility of using small inland vessels (PSBs) for urban freight delivery in urban areas. In doing this, the main actors are identified and analyzed. Furthermore, the different possible outcomes and their decision criteria are stipulated. Based on this, the evaluation techniques to examine the project's feasibility for each actor are specified.

In addition, the chapter elaborates on the identified techniques by developing a model that calculates each evaluation technique and examines the decision criteria. In doing this, a free cash flow model was developed for vessel owners, a TLC model was developed for cargo owners, and an external cost model was developed for society.

The next chapter focuses on data gathering and analysis. The operational profile of the vessels and the required data needed for model estimation are presented in this chapter. Afterward, the models are applied to the specified cases.

Chapter 7 - Urban freight distribution: social cost-benefit analysis of small innovative vessels for urban freight delivery

7.1 Introduction

This chapter presents the data and applies the models developed in the previous chapter on the case study, the city of Ghent[18]. The analysis was performed from two viewpoints; the private viewpoint and the welfare viewpoint. A financial analysis was performed for vessel owners, a total logistics cost analysis was performed for cargo owners, and an external cost analysis for societal benefit. The study considered three main transport options: the truck with 16t capacity, palletized shuttle barges (conventional and autonomous), and the Zulu barge (conventional and autonomous). Afterward, sensitivity analysis was conducted to determine the optimal vessel size for optimal transport from the vessel owner and shippers' viewpoint. All values have been converted from their base years to the current year (2020) using the consumer price index (CPI) described in the previous chapter. This ensures that inflation is accounted for. It also ensures that the values taken from the literature are not sensitive to affecting the overall result of the analysis.

7.2 Data requirements and collection

This section is divided into two parts; the first focuses on the vessels' profiles (PSBs, and Zulus), while the second focuses on the cost data for the different vessel classifications (Conventional PSB, autonomous PSB, conventional Zulu, and autonomous Zulu).

7.2.1 Vessel profile

For this part, the profiles of the vessel types (PSB and Zulu) are described. The PSB profile was first presented; afterward, the Zulu profile was analyzed. The data in the table were collected and composed from partners within the Smart Waterway project[19].

7.2.1.1 PSB profile

Table 7.1 displays the profile and characteristics that are used for the analysis of the PSB barge. The same table comprises some data collected from stakeholders in the industry. Also, some assumptions are made to determine the vessel's operational profile. The sailing trajectory is based on the potential navigation route of the vessels within Ghent (Gasmesterlaan- Dekrook). This distance is about 6km on water (Figure 7.1). The initial PSB vessel is estimated at 15m long, 4m wide, and 1m deep for a starting point. This starting point is based on the technical restriction of the vessel class and the waterway dimension. The sensitivity analysis will further analyze this to determine the optimal vessel size.

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[18] This chapter is originally published as Shobayo P., van Hassel, E., & Vanelslander, T. (2021). Socio-economic evaluation of palletized shuttle barges (PSBs) for urban freight delivery. *International Journal of Transport Economics,* XLVIII(3-4), 525-550.

[19] https://www.imec-int.com/en/research-portfolio/smartwaterway

It is assumed that the vessel will be used to transport consumer and general goods divided into three classes based on their values (high-value, medium-value, and low-value goods). The maximum payload of the vessel is estimated at 20T, with an engine capacity of 65 kW and an average speed of 7 kph. The vessel has an operational hour of 14 hours per day and a loading/unloading rate of 1 pallet per minute. Based on all these, the Total number of hours needed to transport cargo from point A to point B (Gasmesterlaan- Dekrook) is estimated to be 1.7 hours per trip.

Figure 7.1: Vessel sailing trajectory (Gasmesterlaan-Dekrook)

Source: Google Photos

Regarding the volumes of cargo transported, it is estimated that 200,000 pallets of shipments will be available per year. Assuming a 90% occupation rate and with the operational profile earlier specified, 6 PSBs will be needed to complete the yearly transport of the specified cargo volumes. Fuel consumption is estimated at 4.1l/hr, with a fuel price of EUR 0.58/l.

Table 7.1: PSB profile and characteristics

Trajectory		Gasmesterlaan-Dekrook
Vessel characteristics	Cargo type	Palletized general cargo
	Vessel type	PSB
	Goods	Consumer & general cargoes
	Length (m)	15
	Breadth (m)	4
	Draught (m)	1
Maximum payload	[t]	20
Operational hour/year/vessel	[hr]	4.368
No. of engines installed		1
Total engine capacity	[kW]	65
Payload carried/sailing	[t]	18
Operational days in a week	days	6
Distance	[km]	6
Empty sailing		yes
No. of trips per year	#	16.692
no. of trips per week	#	321
No of weeks in a year	#	52
Avg. Speed per trip	[km/h]	7
Sailing hr (round trip)	[hr]	1,3
Loading/unloading rate	[tonne/min]	1,5
Total no. of hr	[hr]	1,7
Avg. life span (years)	[yr]	15
Operational hours per day	[hr/day]	14
Fuel price	[EUR/l]	0,58
Electricity user charge	[EUR/kWh]	0,14
Number of vessels needed	#	6
Occupation rate	%	90%
Safe working load of Euro pallets	[t]	1,5
The volume of cargo to be transported	[pallets/year]	200.000
Fuel consumption	[l/hr]	4,154
Lead time	[Days]	0,07

7.2.1.2 Zulu profile

The profile of the Zulu vessel is displayed in Table 7.2. This table has the same structure as the PSB, except for the change in the vessel size. This is because the Zulus are bigger and already operational. Hence, the exact dimension of these vessels is known, thereby influencing the vessel's operating profile for urban freight delivery.

The sailing trajectory and the distance remain the same as the PSB. However, this vessel is 50 meters long, 7 meters wide, and 2 meters deep, with an initial payload of 300 tonnes. Small waterways within the city are mostly shallow and cannot accommodate a vessel that requires a depth of 2 meters. With this, a target draught of 1m is estimated for the vessel. This reduces the maximum payload to 69 tonnes with an engine capacity of 225 kW and an average speed of 7 kph.

This vessel is also used to transport the same good category and a similar operational profile specified for the PSB vessel. Hence, the total number of hours needed to transport cargo from point A to point B is estimated at 3 hours per trip. Regarding the volumes of cargo transported, it is also assumed that 200,000 pallets of shipments will be available for transport per year. Assuming a 90% occupation rate and with the operational profile of the Zulu vessel, 4 PSBs will be needed to complete the yearly transport of the specified cargo volumes. Fuel consumption is estimated at 8.3l/hr, with a fuel price of EUR 0.58/l.

Table 7.2: Zulu profile and characteristics

Trajectory		Gasmesterlaan-Dekrook
Vessel characteristics	Cargo type	Palletized general cargo
	Vessel type	Zulu
	Goods	Consumer & general cargoes
	Length (m)	50
	Breadth (m)	7
	Draught (m)	2
Maximum payload	[t]	300
Operational hours/year	[hr]	3.640
No. of engines installed		1
Total engine capacity	[kW]	225
Payload carried/sailing	[t]	62
Operational days in a week	days	**5**
Distance	[km]	6
Empty sailing		Yes
No. of trips per year	#	4.836
no. of trips per week	#	93
No of weeks in a year	#	52
Avg. speed per trip	[km/h]	7
Sailing hr (round trip)	[hr]	**1,3**
Loading/unloading rate	[tonne/min]	1,5
Total no. of hr	[hr]	**3**
Avg. life span (years)	[yr]	15
Operational hours per day	[hr/day]	14
Fuel price	[EUR/l]	0,58
Electricity user charge	[EUR/kWh]	0,14
Number of vessels needed	#	4
Occupation rate	%	90%

Safe working load of Euro pallets	[t]	1,5
Target draught of Zulu	[m]	1
cb	[m]	0,7
Vessel displacement	[t]	462
Lightweight	[t]	162
Draught empty		0,70
Draught payload[20]		0,298
Payload (function target draught)	[t]	69
Volumes of cargo to be transported	[Pallets/year]	200.000
Fuel consumption	[l/hr]	8,31
Lead time	[Days]	0,11

7.2.2 Cost data

After all the necessary information about the vessel's profile has been specified, the cost parameters are estimated to represent the investment. In this case, the conventional vessels are compared against the autonomous vessels. In this way, it is possible to determine the economic feasibility of the different vessel options. Table 7.3 provides further information on the cost structure of the conventional PSB and Zulu on the one hand and the autonomous PSB and Zulu on the other.

Table 7.3: Cost parameters of vessels

<table>
<tr><th>Costs</th><th>Elements</th><th>Values</th><th>Conventional PSB</th><th>Conventional Zulu</th><th>Autonomous PSB</th><th>Autonomous Zulu</th></tr>
<tr><td rowspan="2">Capital cost</td><td>Initial capital cost</td><td></td><td>250.000</td><td>1.300.000</td><td>250.000</td><td>1.300.000</td></tr>
<tr><td>Software engineering</td><td></td><td></td><td></td><td>5.000</td><td>15.000</td></tr>
<tr><td rowspan="9">Automation cost</td><td>Control unit</td><td></td><td></td><td></td><td>45.000</td><td>65.000</td></tr>
<tr><td>Communication</td><td></td><td></td><td></td><td>7.000</td><td>10.000</td></tr>
<tr><td>Remote control</td><td></td><td></td><td></td><td>5.000</td><td>5.000</td></tr>
<tr><td>Positioning</td><td></td><td></td><td></td><td>4.000</td><td>8.000</td></tr>
<tr><td>Camera</td><td></td><td></td><td></td><td>5.000</td><td>10.000</td></tr>
<tr><td>LIDARs</td><td></td><td></td><td></td><td>6.000</td><td>12.000</td></tr>
<tr><td>Status sensors</td><td></td><td></td><td></td><td>5.000</td><td>5.000</td></tr>
<tr><td>Cable/antennas</td><td></td><td></td><td></td><td>5.000</td><td>25.000</td></tr>
<tr><td>Total automation cost</td><td></td><td></td><td></td><td>87.000</td><td>155.000</td></tr>
<tr><td rowspan="4">Infrastructure cost</td><td>Communication</td><td></td><td></td><td></td><td colspan="2">2.000</td></tr>
<tr><td>UWB localization</td><td></td><td></td><td></td><td colspan="2">500</td></tr>
<tr><td>Camera tech</td><td></td><td></td><td></td><td colspan="2">6.000</td></tr>
<tr><td>Computation</td><td></td><td></td><td></td><td colspan="2">1.500</td></tr>
</table>

[20] This draught is calculated based on a cargo volume that can be transported at a specific water depth restriction.

	Initial infrastructure cost (EUR/unit)				10.000	
	Total infrastructure cost for 10 units				100.000	
Total investment/Capital cost			250.000	1.300.000	437.000	1.555.000
Terminal value	Fixed demolition value of the investment	2.5%				
Maintenance cost	Power-dependent cost (EUR/kW/yr)	4,94	321	1.112	321	1.112
	Engine overhaul after 30,000hrs (EUR/kW/yr)	63	596	1.720	596	1.720
	Other maintenance costs		12.500	65.000	12.500	65.000
	Automation Infrastructure maintenance (EUR/year)	50.000			50000	50000
Total maintenance cost/year			13.417	67.831	63.417	117.831
Insurance	percentage value/yr of investment cost	2%				
Financial cost	percentage loan finance of investment	80%				
	Payback period (years)	15				
	Interest	5%				
Annual waterway permit	(Eur/m)	14,73	220	737	220	737
Salaries	Skipper - Gross salary (EUR/yr)		100.000	120.000	100.000	120.000
	Ship boy - Gross salary (EUR/yr)					
Total salaries			100.000	120.000	33.333	30.000
Inspection cost	Avg. annual inspection cost (EUR/year)		1.250	6.500	1.250	6.500
Energy cost	Yearly Energy cost		10.524	17.540	10.524	17.540
Tax		33%				
	WACC	6%				

The different elements specified in the Table are subsequently discussed below:

Capital cost: The initial cost of a conventional PSB vessel amounts to EUR 250.000, while that of a conventional Zulu is estimated at EUR 1.300.000. An extra software engineering cost for the autonomous vessels must be installed on board. This is estimated at EUR 5.000 for the autonomous PSB and EUR 15,000 for the autonomous Zulu.

Automation cost: Conventional vessels have no automation costs. For autonomous vessels, the automation cost includes the cost of implanting automated sailing. This cost is divided into two main parts: automation and infrastructure. While the automation cost is calculated per vessel, the infrastructure cost is fixed and calculated per unit of the item installed in the location. The automation cost includes the control unit, communication, remote control, positioning, cameras, sensors, and cables. These are estimated at EUR 87.000 per PSB vessel and EUR 155.000 per Zulu vessel. The difference in the cost for these two vessels is due to the size of the vessels. More installations would be needed for a larger vessel than a smaller one. The infrastructure costs include; communication, localization detection, computation, and camera technology. These are installed per unit, and estimated that there would be ten installed units along the trajectory. Each unit is estimated at EUR 10.000, leading to EUR 100.000 for the infrastructure cost.

Terminal value: A correct representation of the final value of both ships is complicated. This is mainly due to the long lifespan of inland vessels. The absolute value depends on whether the vessels can still be sold on the second-hand market to continue the activities or whether the vessels will be scrapped. Suppose the vessel is sold on the second-hand market. In that case, the value depends on the future demand for inland waterway transport, the expectations in the market where the vessel is active, and the costs to be incurred to meet the requirements of the classification societies. If the barge is scrapped, the final value would depend on several factors, such as the value of the engine parts, the hull material, the value of other components, and the willingness to pay for the ship by the scrapyard. All of these are, however, very difficult to estimate in the short and long run. Hence, the model assumes a fixed terminal value of 2,5% calculated at the initial investment.

Maintenance costs: Maintenance costs are divided into preventive and corrective maintenance. Preventative maintenance occurs regularly and must ensure that the part does not show any defects in the future. This mainly concerns the hull, superstructure, propeller, machinery, and electrical components. Corrective maintenance costs occur when a flaw in the installation is found. Based on this, the maintenance costs include the power-dependent cost, engine overhaul cost, infrastructure maintenance costs, and other related maintenance costs. These costs amount to EUR 13.417 for conventional PSB, EUR 67.831 for conventional Zulu, EUR 63.417 for autonomous PSB, and EUR 117.831 for autonomous Zulu.

Insurance: To insure the damage to the vessels, hull insurance is taken out. There is no premium difference between conventional and autonomous vessels. However, the amount of the premium depends on the insured value. The annual premium is assumed to be 2% of the investment cost of the vessel.

Financial cost: The inland shipping company cannot finance the ship entirely on its own and therefore takes out a loan from the bank. Hence, a loan of 80% of the initial investment value over 15 years.

With this, an average interest rate of 4.5% is assumed, and a weighted average cost of capital (WACC) of 6%.

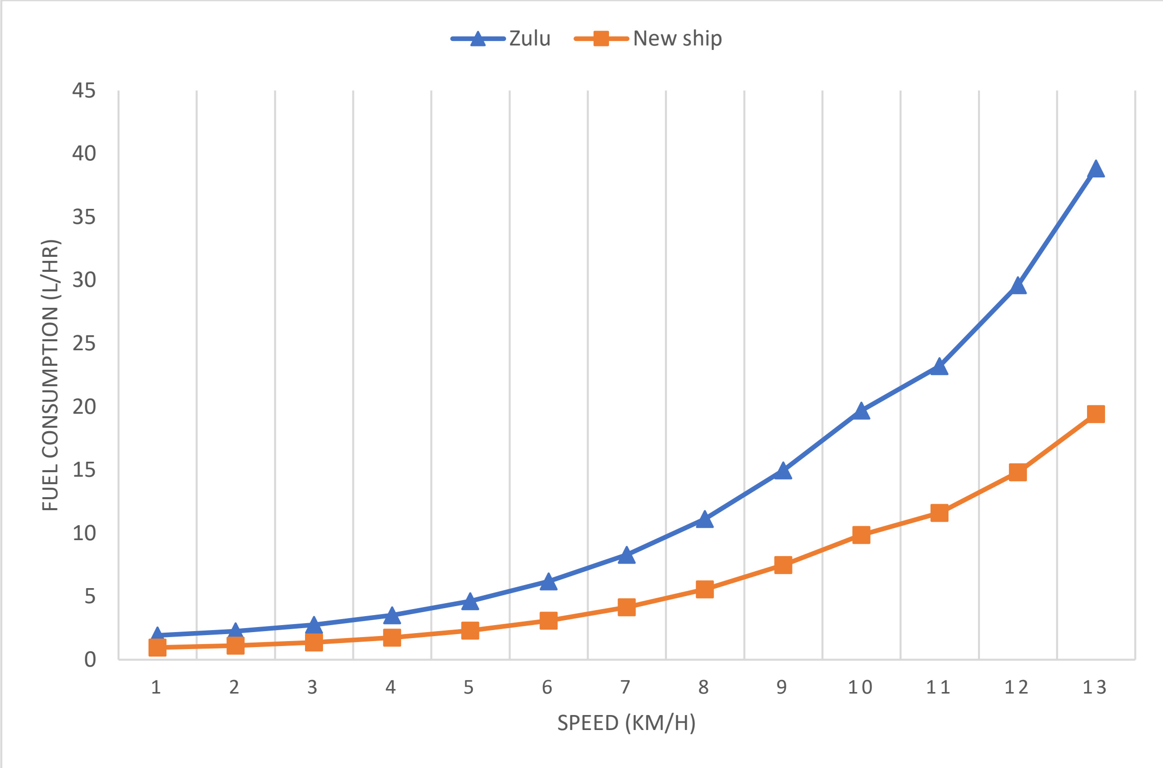
Waterway permit: Waterway permits are required for vessels sailing on or moored on navigable waterways in the Flemish region. Different rates are charged on the vessel's hull length based on the number of days required for the permit. For this analysis, the vessel has an annual permit tariff of EUR 14,73/length.

Wages and Salaries: A crew is needed to operate a conventional inland vessel. The wages paid to the crew take up a large part of the annual costs. The conventional vessels in the calculation model assume that the vessel operates with just a skipper. The personnel is regarded as employee staff and not self-employed or entrepreneurs. Thus, the average annual employee gross salaries are estimated at EUR 100.000 for the skipper of PSB barges and EUR 120.000 for the skipper of Zulu barges. For autonomous vessels, the service of the skipper is needed to control the vessel from the shore control center. In doing this, it is assumed that the skipper can monitor up to four vessels at a time, leading to a skipper-vessel ratio of 1:4; hence, the salary of one skipper is spread across four autonomous vessels.

Inspection costs: For the inland vessels to meet the technical requirements, they must undergo various inspections. The number of inspections that ships must undergo depends strongly on the country where the certificates have been issued. For example, an inland vessel in Belgium is subjected to a floating inspection every 2.5 years and an assessment in a dry dock every five years. In the Netherlands, on the other hand, the ship must undergo a dry dock inspection every seven years. Each inspection involves costs. The costs associated with docking include docking costs, docking days, cleaning and conservation, thickness measurements, standard work, inspection costs, and loss of income. This study's annual average inspection cost is estimated at EUR 1.250 for PSB vessels and EUR 6.500 for Zulu barges.

Fuel costs: One of an inland vessel's highest operational costs is fuel. This cost depends on several factors. Firstly, the power consumption of the engine has a significant impact. An inland vessel does not sail the entire journey at maximum power. This is directly related to the current on certain rivers. A final important aspect is the inland vessel's speed—the faster the ship sails, the more fuel it will require (Figure 7.2).For this analysis, an average speed of 7kph has been selected. This is because the vessels will sail in the city's confined waterways. Hence, a restriction on the sailing speed in this type of water. Based on this, the fuel consumption of 4,1l/hr is estimated for the PSB barges and 8,3 l/hr for the Zulu vessels. Hence, the annual fuel cost of PSB is estimated at EUR 10.524, while Zulu's is estimated at EUR 17.540.

Figure 7.2: Fuel consumption in relation to vessel speed



Taxes: An inland shipping company is also subject to income tax. Hence, the calculation model uses the corporate income tax of 33% on the taxable profit. However, this profit tax depends on if the shipping company achieves positive earnings before tax in a specific year. This implies that the tax rate is only administered within the model if the earnings before tax in a single year are positive; otherwise, there will be no tax charges.

7.3 Analysis and Discussion

This section focuses on the financial and economic analysis of the earlier cases. For this analysis, an annual cargo volume of 200,000 pallets is specified in the model. Also, an estimated freight rate is determined in the model. This freight rate is set at a competitive rate with road transport. This rate is determined by dividing the yearly operational costs by the annual number of pallets. In addition, a specific profit margin is added to this rate. The freight rate of road transport influences this profit margin, the current average freight rate of IWT (without profit margin), and the cargo volumes to be transported. Hence, the estimated average transport price for IWT freight based on the parameters set is EUR 7,36/pallet, while that of road transport is EUR 10,76/pallet, thus, confirming a competitive transport price of IWT with road transport. Based on this, the following subsections present the financial analysis and total logistics cost (TLC) from the private and welfare point of view.

7.3.1 Analysis & discussion from the private case

7.3.1.1 Financial analysis for vessel owners

In this section, the analysis of the parameters from the private point of view is presented and discussed. Figure 7.3 reveals the financial cash flow of the specified shuttle barge categories (conventional PSB, conventional Zulu, autonomous PSB, autonomous Zulu). The figure shows that conventional PSB has the highest cumulative financial discounted cash flow at EUR 456.456, while autonomous Zulu has the lowest cumulative cash flow at EUR (1.052.223). Generally, the figure reveals that the PSBs (both conventional and autonomous) would generate more cash flow than the Zulus even though the Zulus have more carrying capacity and can generate more income. A possible reason for this is the short distance in the vessel trajectory from the pick-up to the drop-off point, making it more efficient and effective for the PSBs while being less efficient for the Zulus from both the operational and the financial perspective.

Regarding the payback period of the investment, the figure reveals that the conventional PSB has the shortest payback period at four years, while the autonomous PSB has a payback period of 8 years. Meanwhile, the Zulu vessels will not be able to repay the investment as the costs of the vessels will be too expensive for the type of small operations they would be used for, making them inefficient.

Figure 7.3: Cumulative cashflow of PSB and Zulu (private viewpoint)

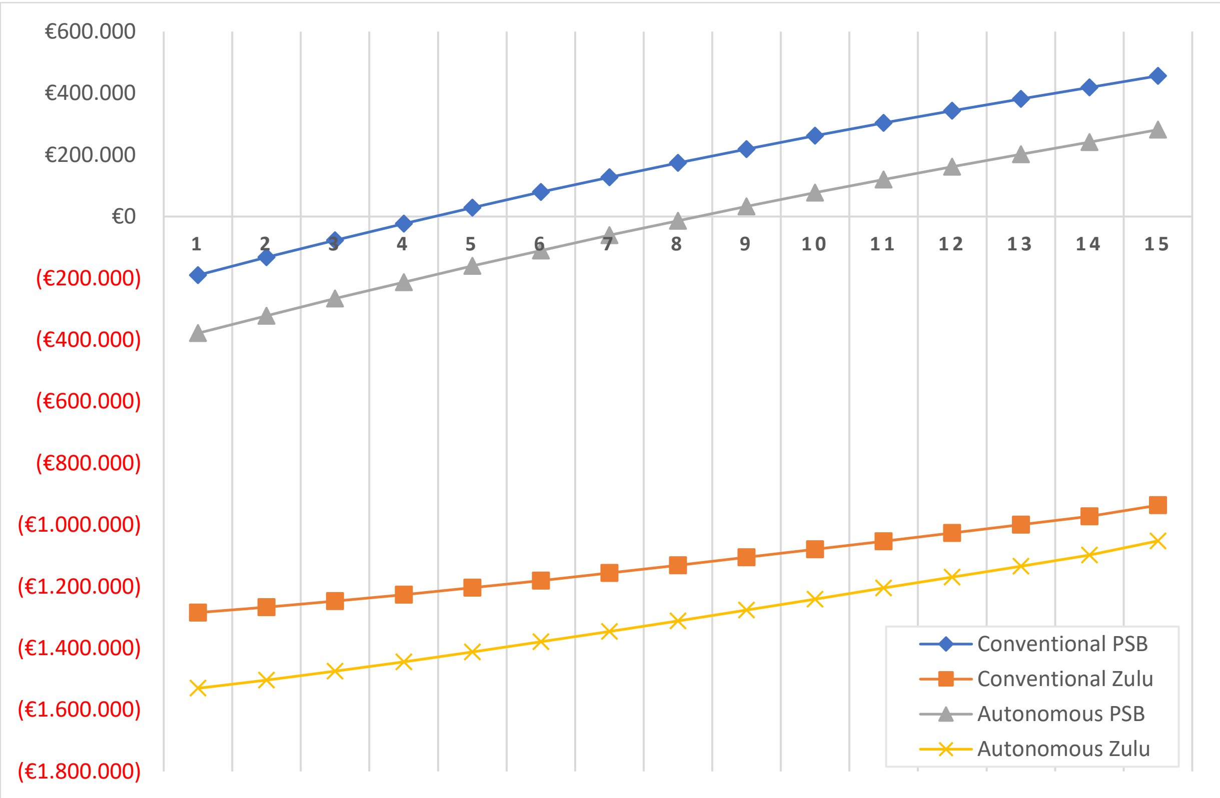
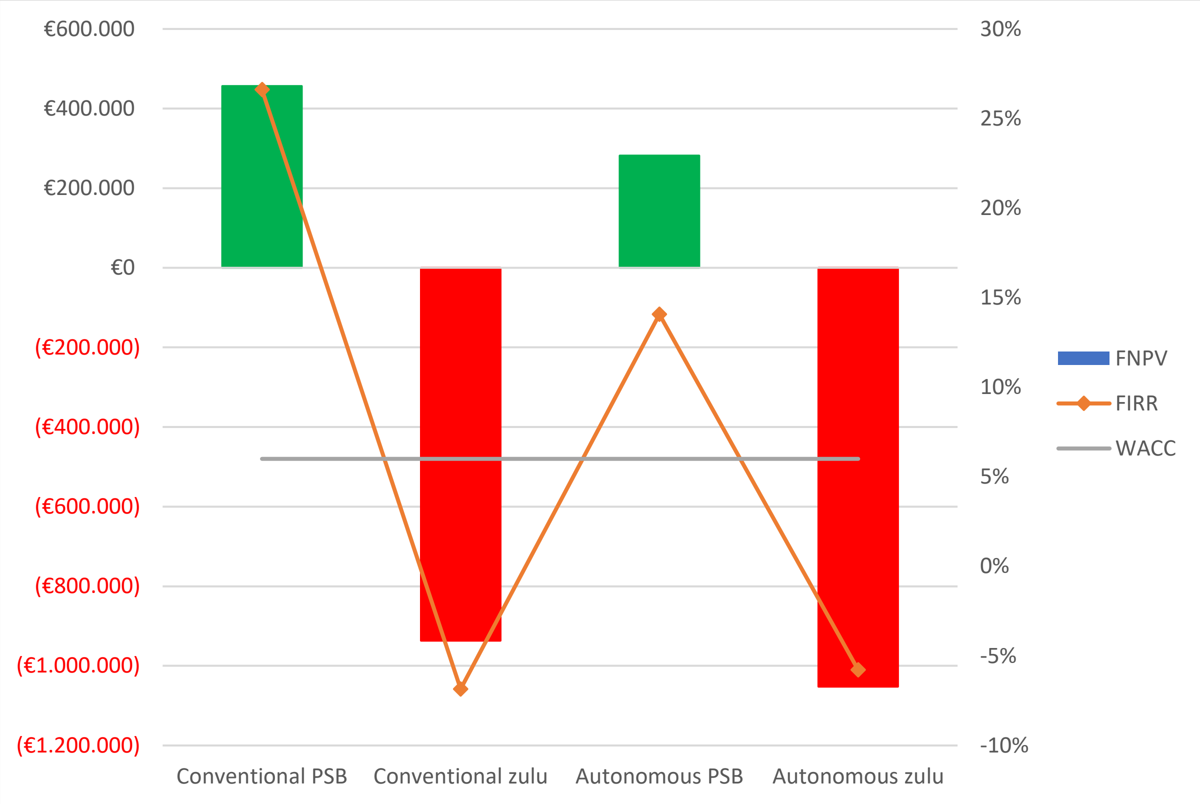


Figure 7.4 presents the NPV and IRR of the vessel categories. As earlier stated, an average required freight rate of EUR 7,36/pallet is calculated for the vessels to have a competitive price with road transport. This rate is used across all four vessel types because, in reality, this will be the case, irrespective of the kind of shuttle barge. The figure revealed that the Zulus have negative NPVs due to the lack of efficient transport operations based on the pick-up and drop-off trajectory of the vessels. These vessels also have IRR rates below the WACC, suggesting that investing in these vessels would negatively benefit the vessel owners from a private point of view. On the other hand, PSBs (conventional and autonomous) have positive NPVs and high IRRs that are well above the WACC, suggesting a positive net benefit from the private point of view for using these vessels. As earlier

stated, the feasibility of the PSBs is attributed to the short transport distance of the trajectory, making them operationally and financially viable for these types of operations.

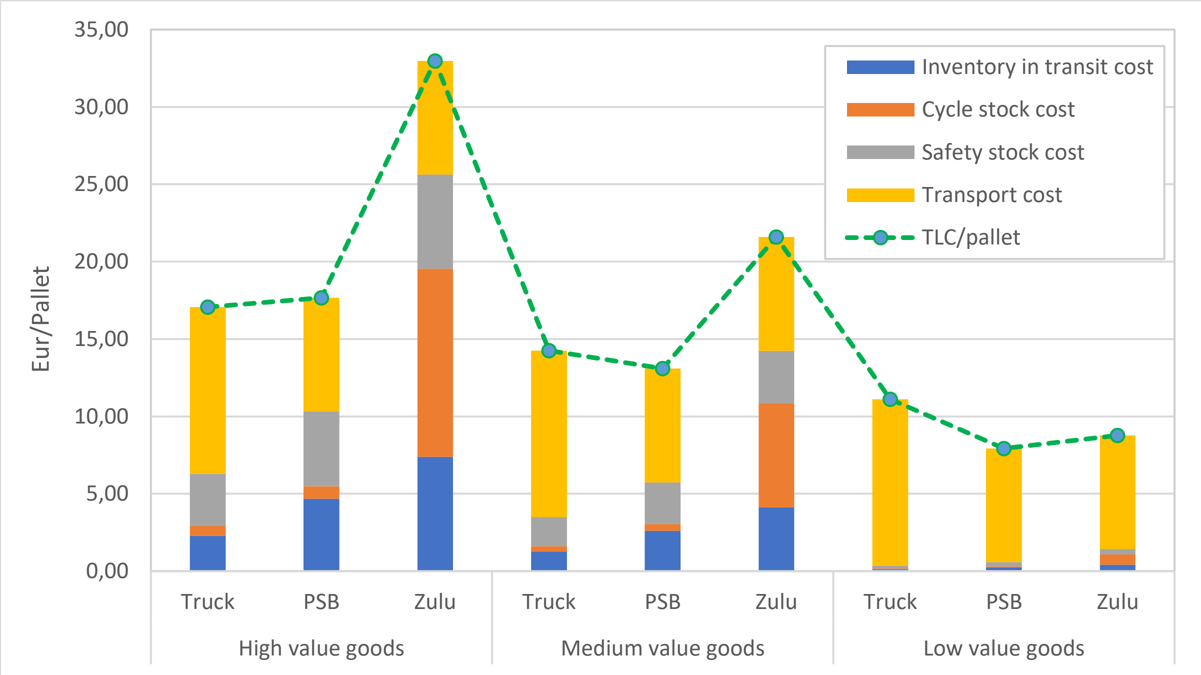
Figure 7.4: NPV & IRR of PSB and Zulu (private viewpoint)



7.3.1.2 Total logistics cost for shippers/cargo owners

The TLC analysis is divided into three types of goods (high-value, medium-value, and low-value goods) for transport options. Based on the study of Blauwens et al. (2006), the value of the goods is estimated to be EUR 10.800/pallet for high-value goods, EUR 6.000/pallet for medium-value goods, and EUR 600/pallet for low-value goods. Figure 7.5 presents the TLC for the shippers in the private case. The Zulu option appears to be the most expensive option for high and medium-value goods, while the truck is the most expensive for low-value goods for the shippers. As seen in the figure, all the cost elements (inventory-in-transit cost, cycle stock cost, and safety stock cost), except transport cost, make Zulu the most expensive option. Three main factors can explain this: the number of Zulu vessels deployed, the total number of operational hours, and the occupation rate of the vessels.

Figure 7.5: TLC analysis (private viewpoint)



The Zulu spends many hours sailing and discharging, which automatically affects the service frequency of the vessels. In this case, four Zulu vessels are deployed to transport 200,000 pallets (Table 7.4) annually, whereas six PSBs will be required, and four trucks are needed to transport the same annual cargo volume. This implies that while the Zulu vessels can only transport specific volumes simultaneously, the PSB can transport multiple volumes simultaneously. In contrast, the fast speed of the truck allows it to complete more trips with fewer vehicles deployed. Therefore, considering the speed of the vessels, Zulu becomes an expensive option for the shipper regarding the holding cost and time that the cargo will be transported and handled from the pick-up place to the drop-off point. This is especially the case for high and medium-value goods, which are time sensitive and have high values. A further reason is the low capacity utilization of the vessel. The Zulus cannot utilize most of its capacity if they are on small shallow waters within the city. This prevents it from taking advantage of the large capacity it has to be able to minimize its costs.

The figure further reveals that trucks have the lowest TLC for high-value goods, while PSB offers the lowest TLC for medium and low-value goods. However, the difference with trucks for medium-value goods is insignificant. With this, shippers can decide which option suits them based on their preference (lower transport cost or quick transport). The low TLC for the PSB in low-value goods can be attributed to two main factors: the competitive transport cost, which is lower than the trucks. This low transport cost makes the PSB more competitive and attractive to shippers. The second factor is that low-value goods are not time-sensitive, making the PSBs suitable for these goods.

Table 7.4: Number of vehicles deployed

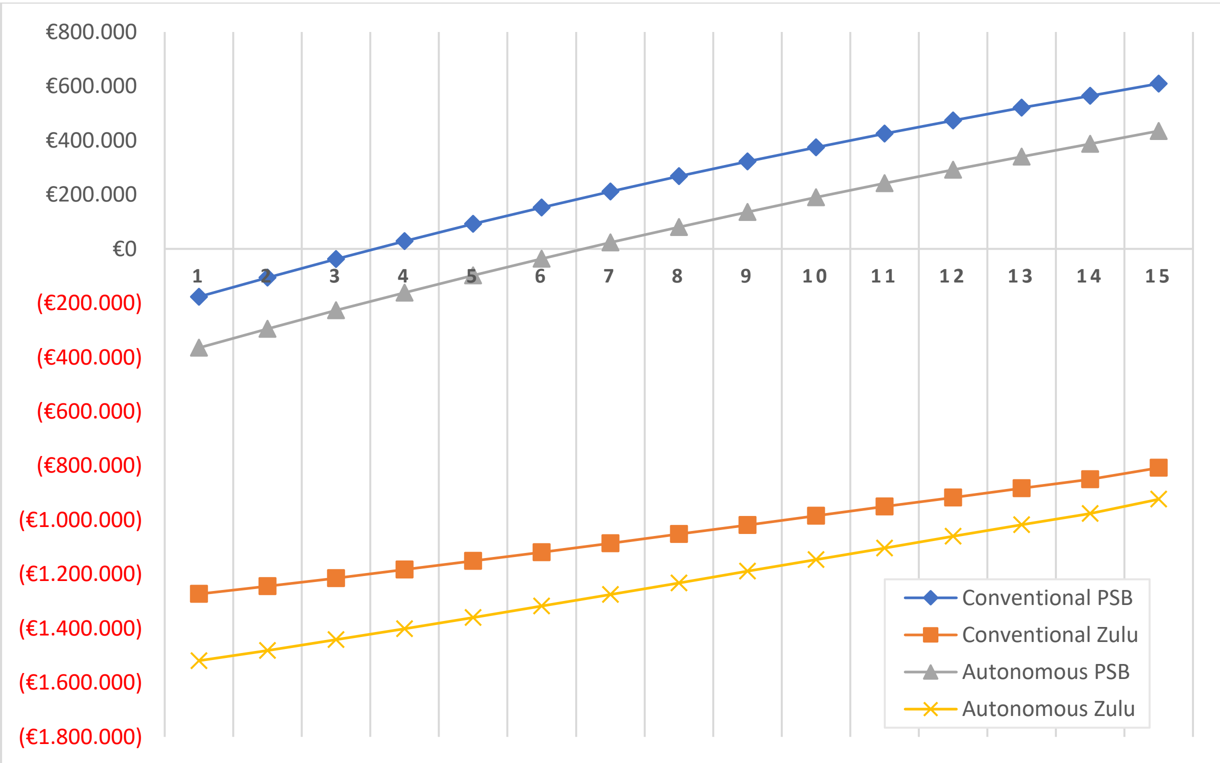
Vehicle type	Number
Truck	4
PSB	6
Zulu	4

7.3.2 Analysis & discussion of the welfare case

7.3.2.1 Financial analysis for vessel owners

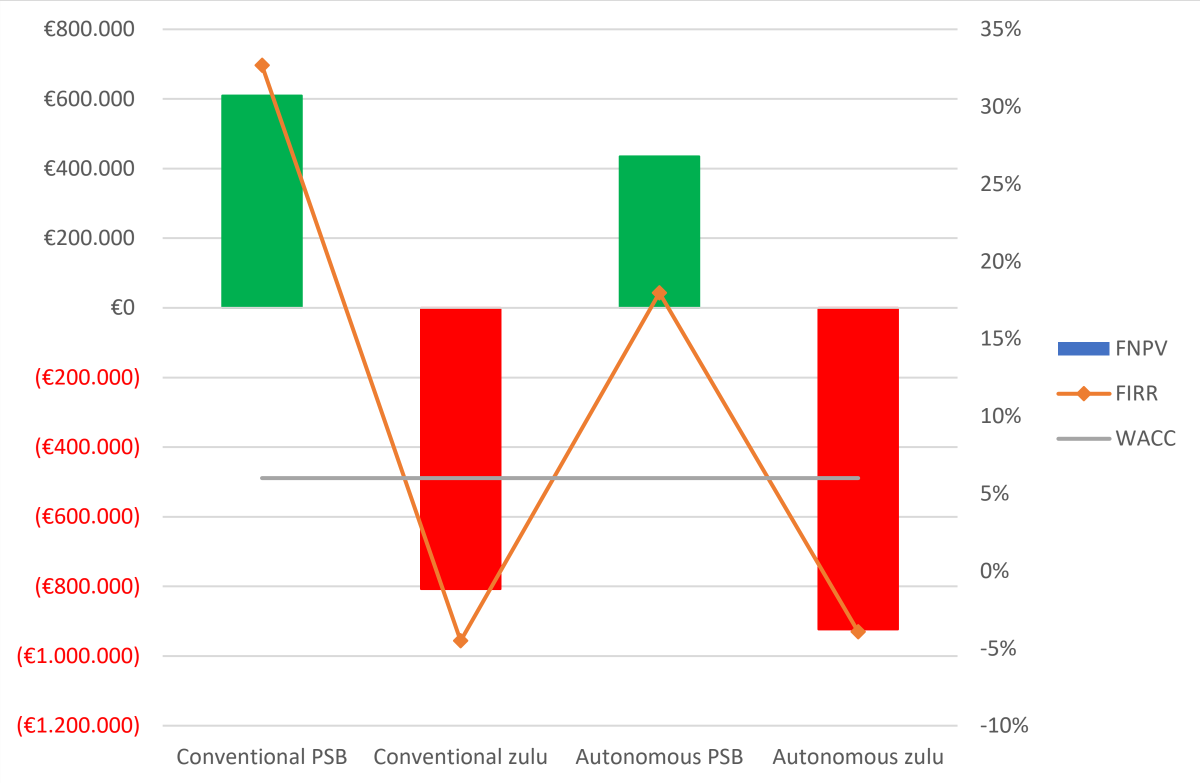
Figure 7.6 reveals the discounted cash flow of shuttle barges of vessel owners from the welfare point of view. As seen in the figure, the PSBs (conventional and autonomous) remain positive cumulative cash flows, with the conventional PSB maintaining the highest cash flow. This is similar to the private case, where the Zulus are less efficient from the operational and financial perspective. Furthermore, in the welfare case, it can be seen that the vessels generated a higher cash flow than in the private case. The main reason is the possibility of external cost savings from internalizing external costs. This becomes possible due to the total external cost difference between the road and IWT, which becomes positive for IWT.

Figure 7.6: Cumulative financial discounted cashflow of PSB and Zulu (welfare viewpoint)



Regarding the payback period, the figure reveals that the conventional PSB has the lowest payback period at four years, while the autonomous PSB has a payback period of seven years. This is logical as more significant investments are expected to be made in the autonomous PSB. The Zulu vessels (conventional and autonomous) will not be able to repay the cost of investments. Regarding the NPV and IRR, Figure 7.7 is consistent with the private case where the PSBs (conventional and autonomous) produce positive NPVs, and the Zulus have negative NPVs. Hence, the social case has no significant effect on the viability of the Zulu vessels. Regarding the IRR, the conventional PSB has the highest IRR rate above the WACC, with 33%, while the autonomous PSB has an IRR rate of 18%. The IRR rates of the Zulus (conventional and autonomous) are both negative and below the WACC at (-5%) and (-4%), respectively, suggesting that these vessels are not suitable investments for this type of operation even from the welfare point of view.

Figure 7.7: NPV & IRR of PSB and Zulu (welfare viewpoint)



7.3.2.2 TLC analysis for cargo owners

In Figure 7.8, the TLC in the welfare case is presented. In this case, road transport becomes more expensive due to internalizing external costs. Based on this, the PSB offers an effective cheapest option across all three types of goods, suggesting a positive use case for different goods from the welfare point. The Zulu vessel remains the most expensive for high-value goods and is slightly expensive compared to road transport for medium-value goods. This is mainly due to the associated logistics cost.

Additionally, the welfare case benefits society in terms of external cost savings by using the PSB. Figure 7.9 reveals the yearly external cost of transporting the specified cargo volume for the two cheapest transport options. The figure indicates that about EUR 22,000 could be saved yearly from the negative externalities of using the PSBs.

Figure 7.8: TLC analysis (welfare viewpoint)

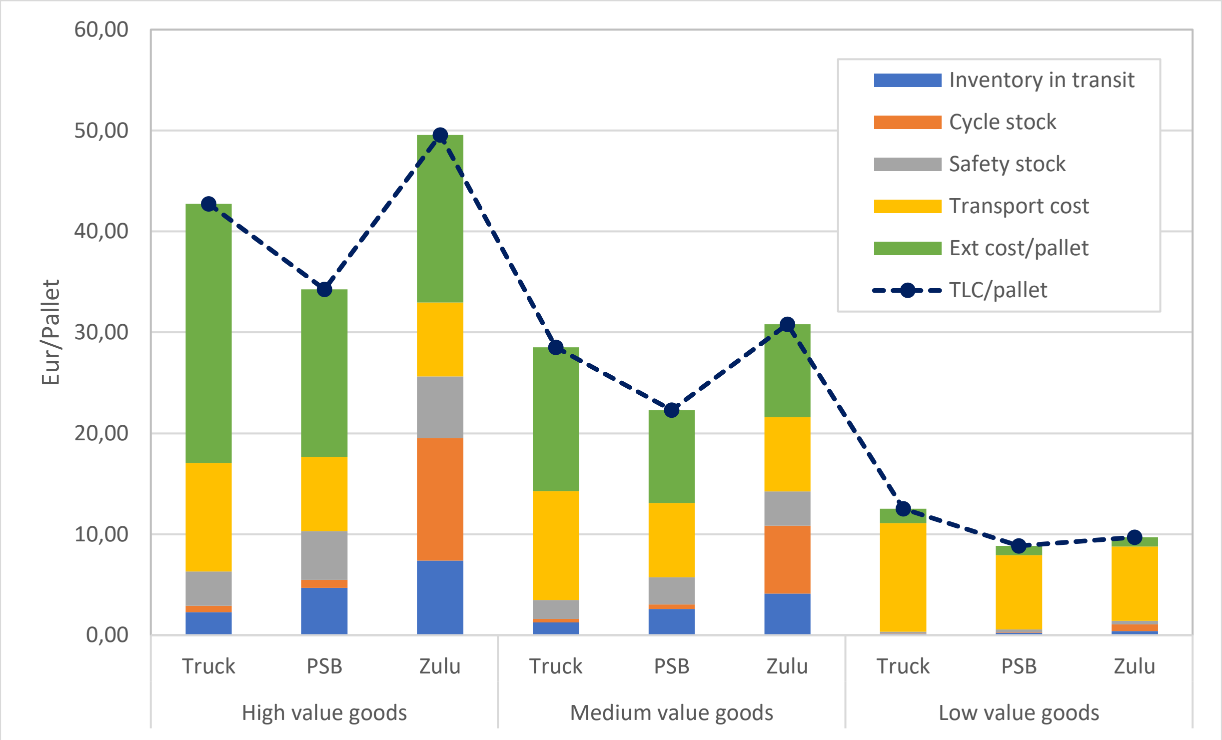
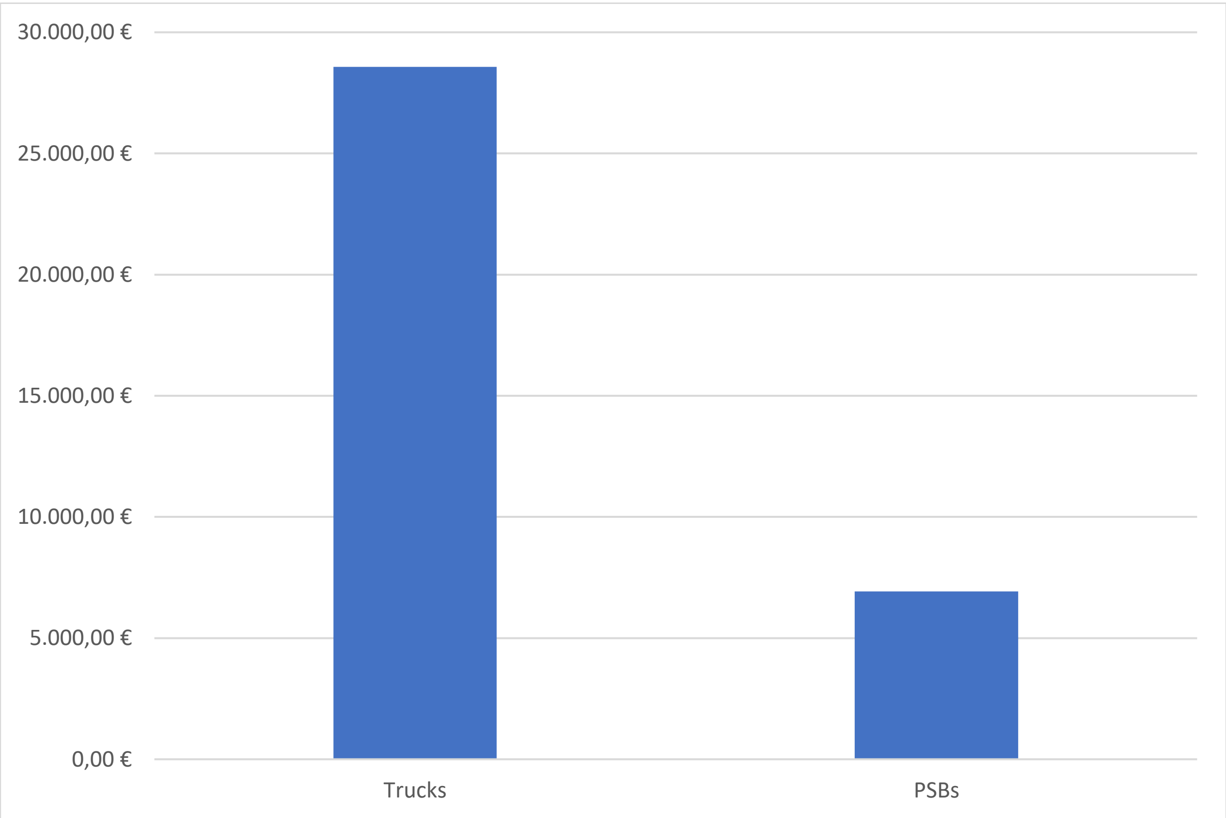


Figure 7.9: Total external cost



7.3.3 Comparative analysis between the private and the welfare point of view

With the analysis of the private and welfare case, the next step is to compare these two situations to determine the overall effect of internalizing external costs. Table 7.5 compares the private and welfare viewpoint of the vessel owner. The table shows a percentage increase in the positive cumulative cash flow of 34% and 54% for the conventional and autonomous PSB, respectively, suggesting an even higher revenue stream for vessel owners in the welfare case. This is due to the external cost savings achieved in the welfare situation. This percentage increase is also reflected in the IRR, with a 23% and 28% increase for conventional and autonomous PSBs.

This trend can also be seen in the Zulu vessels but in the other direction. This is due to the negative cash flows and IRRs recorded for the conventional and autonomous Zulu vessels, with the welfare case reducing the deficit by 14% and 12% for the cash flow and 34% and 32% for the IRR for conventional and autonomous Zulu, respectively. Both viewpoints, however, still do not present a positive business case for using the Zulu vessels, making the Zulus financially and operationally impossible to use for this case.

Table 7.5: Private and welfare case comparison

Vessel type	**NPV**			**IRR**		
	Private viewpoint (EUR)	**Welfare viewpoint (EUR)**	**% change**	**Private viewpoint %**	**Welfare viewpoint %**	**% change**
Conventional PSB	456.456	609.686	34%	27%	33%	23%
Conventional Zulu	(936.658)	(807.523)	14%	(7%)	(5%)	34%
Autonomous PSB	281.776	435.006	54%	14%	17%	28%
Autonomous Zulu	(1.052.223)	(923.460)	12%	(6%)	(4%)	32%

Based on this, it is then essential to examine the decision criteria of the project. For this, we determine whether the project should be implemented based on the net benefit of the actors and the decision criteria specified in Table 6.5. The PSB will be used as the benchmark shuttle barge to evaluate the project, as this is the focus solution. From the analysis conducted, it can be seen that vessel owners have a positive net benefit from both private and welfare cases. The welfare case provides even higher NPV and IRR values.

Regarding the cargo owners (shippers), the analysis revealed a positive use case of PSBs for low-value goods from the private viewpoint. However, by internalizing the external costs, PSBs offer the cheapest transport option for the different types of goods. Hence, it can be argued that the PSB leads to a positive net benefit from a welfare point of view for the cargo owners assuming the external costs are internalized. The analysis further revealed a positive societal net benefit of using the PSB barge. This is due to the low external cost compared to the use of trucks. Based on all these, the PSB concept (conventional and autonomous) has a positive net benefit for all actors from the private and welfare viewpoint.

7.4 Sensitivity Analysis

The previous analysis observed that the optimal vessel size needed for urban freight delivery is not examined. To this end, the sensitivity analysis conducted in this section aims to analyze different vessel sizes and their economic impact on the use of small vessels for urban freight delivery.

From the previous analysis, the economic research of the identified vessel types has established that the Zulu vessels are not economically and practically feasible for urban freight delivery via the small waterway canals. The carrying capacity specified in this study for the Zulu vessel is estimated at 69 tonnes. Therefore, it can be concluded that a vessel with a carrying capacity of 69 tonnes cannot be used for cargo transport to urban areas. To this end, this section conducts a sensitivity analysis to examine the optimal vessel size and appropriate design for urban freight transport. To do this, the investment analysis of the barge owner is analyzed for different vessel capacities and specifications. Also, an optimal transport price to attract cargo from the road to IWT is determined for shippers.

Starting with the optimal transport price for shippers, it has to be determined what would motivate them to switch from road transport to IWT. For this, a significant reduction in the transport price would be the main determining factor. To determine this, we compared the average lead time of road transport and IWT. Road transport has a 69% reduction in the average lead time compared to IWT. Hence, it was determined that to attract cargo from the road to IWT, the transport price of IWT must have the same reduction level (69%) as road transport. This is to compensate for the high lead time of the inland waterway transport system. Based on this, the transport price of IWT is computed as EUR 3.35/pallet.

Having determined this, the investment analysis is conducted for capacities less than 70 tonnes based on the transport price. The idea is to determine the vessel design (length, width, propulsion, resistance, and logistical profile) from the different payload capacities. In doing this, the vessel owner's cash flow, payback period (PBP), and internal rate of return (IRR) is analyzed for different vessel capacities, thereby generating an output that would yield the highest investment result for the barge owners. With this, the optimal vessel profile can then be determined. Based on this, the investment sensitivity analysis is presented and discussed in the following subsection

7.4.1 Analysis and Discussion

The cash flow analysis of the different vessel capacities is first presented (Figure 7.10). The analysis reveals that vessels with higher carrying capacity generate positive cash flow implying a positive investment for the vessel owners; however, the lower capacity vessels would yield negative cashflow and would not be able to cover the cost of investments. A positive cash flow will only be possible from 40 tonnes, while 30 tonnes and below capacities would not be viable from the vessel owners' point of view. A possible reason why high-capacity vessels generate higher cashflows and are more feasible is due to the economies of scale advantage that these vessels enjoy. They can generate more revenue by transporting more cargo in a single trip than the low-capacity vessels that cannot generate enough revenue to cover their costs.

The figure further reveals that vessel capacities do not have a linear relationship with the cash flow level. This implies that the higher capacities do not necessarily lead to an equal level of cash flow. The figure shows that a 60-tonne vessel capacity generates the most cash flow and is more profitable for the vessel owner than a 70-tonne vessel. Hence, it can be concluded that the economies of scale advantage can be enjoyed up to a capacity of 60 tonnes. A capacity above this would result in diseconomies of scale. With this, it can be said that the optimal vessel capacity from the cash flow viewpoint is a 60-tonne vessel.

Figure 7.10: Cash flow analysis of the different vessel payloads

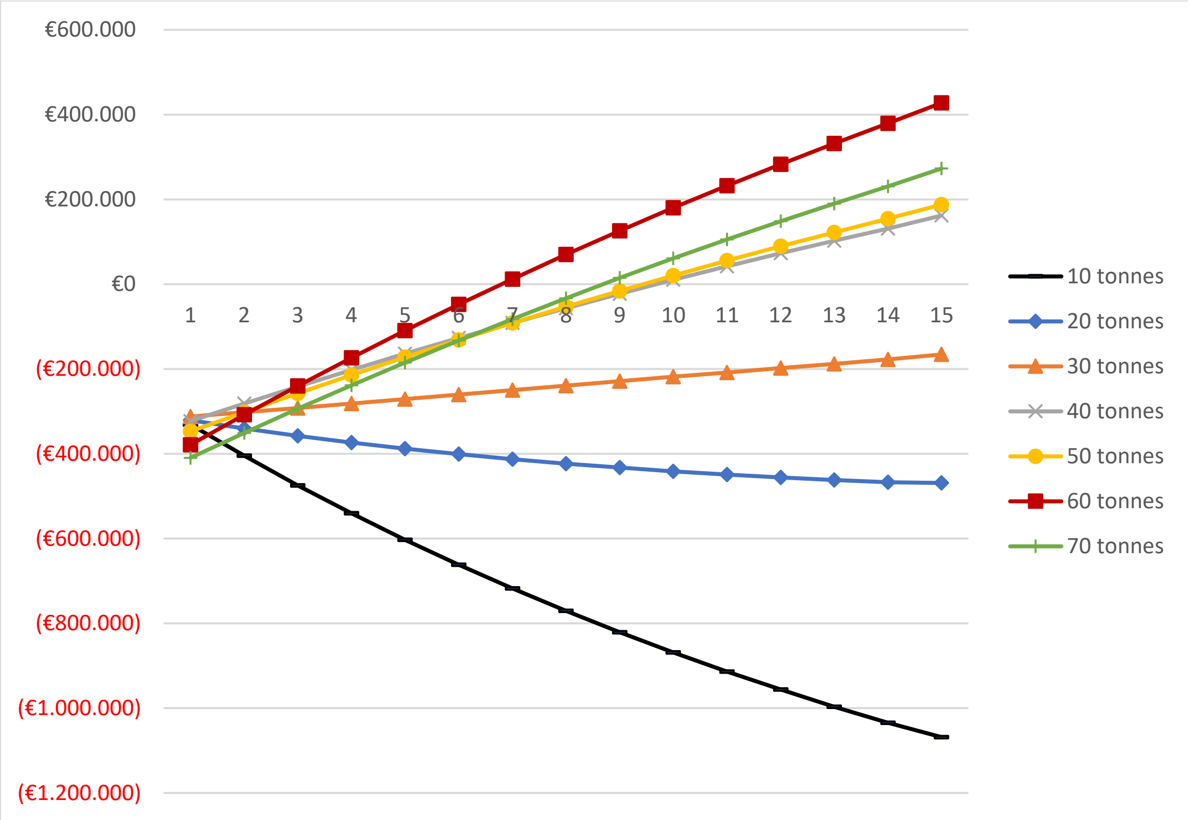
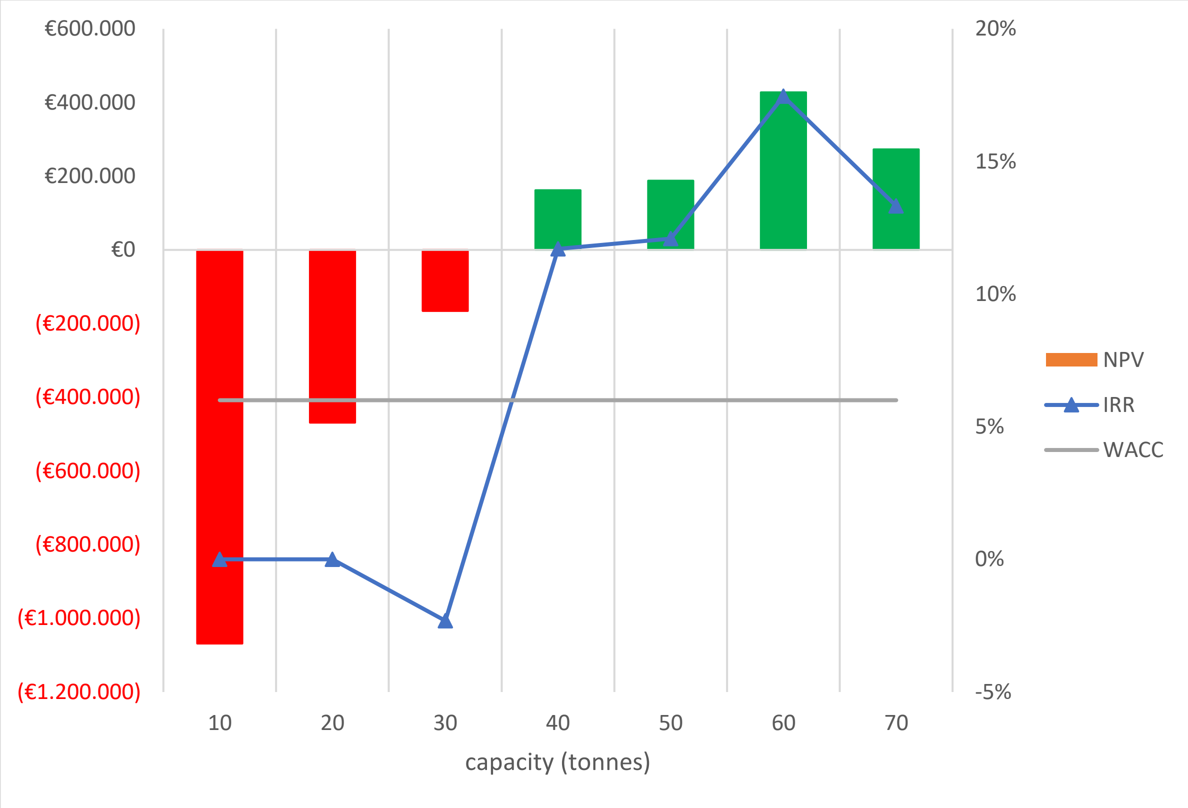


Figure 7.11 presents the NPV and IRR of the different vessel capacities. Here also, the 60-tonne vessel has the highest NPV and IRR rate at EUR 427,636 and 17%, respectively. This confirms that it is the optimal viable size for the vessel owners. The small capacity vessels up to 30 tonnes will not yield a viable investment for the barge owners. Hence these should be avoided.

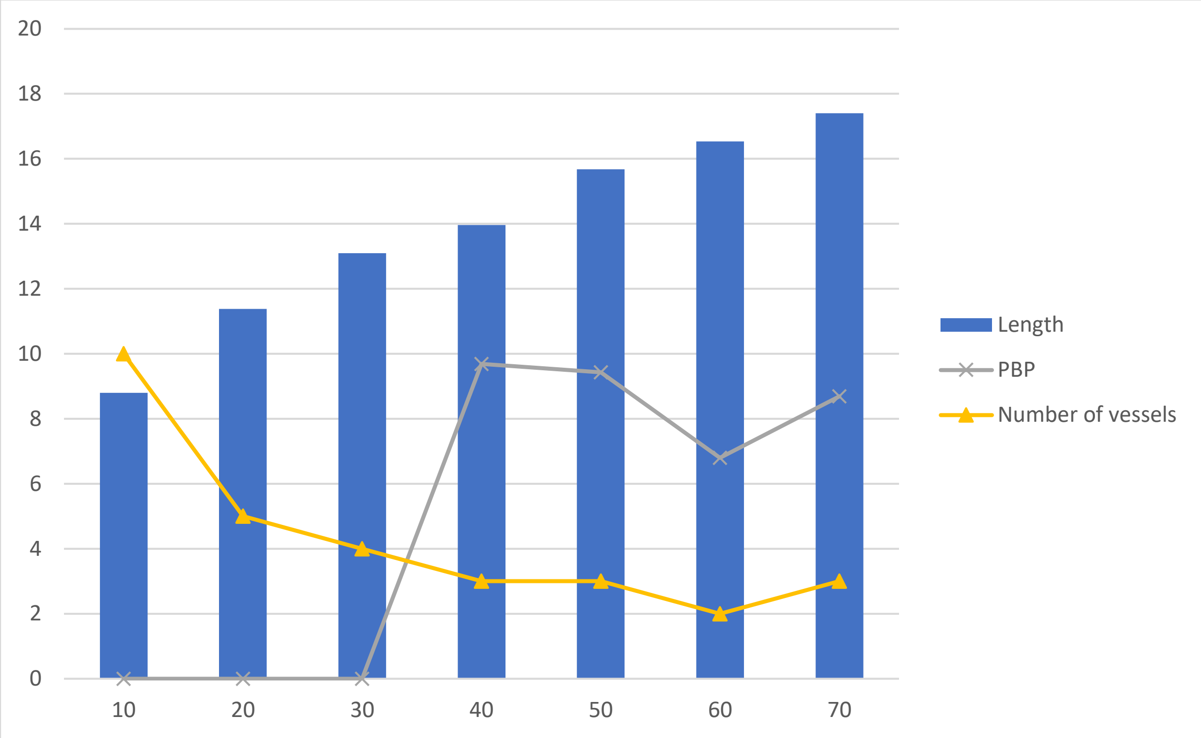
Figure 7.11: NPV, IRR, and WACC analysis



Further analysis to justify the optimal vessel capacity is further presented in Figure 7.12. This figure illustrates three different results: the payback period of the financing option, the number of vessels deployed to transport the yearly cargo volume (200,000 tonnes), and the optimal length of the vessel based on its capacity. The figure showed a logical result in the vessel length, which is directly linked to the vessel's capacity. This implies that small-capacity vessels have a shorter length, which increases according to the capacity of the barges. Regarding the number of vessels needed to achieve the annual transport target, the table reveals that the small-capacity vessels would need more vessels for the same transport quantity. For instance, ten of the 10-tonne vessel will need to be deployed to achieve the annual transport target, while five of the 20-tonne and four of the 30-tonne vessel is required for the same transport quantity. However, the same number (three) is needed for the 40, 50, and 70-tonne vessels to achieve the transport target, whereas only two 60-tonne vessels are required for the same transport quantity. Hence, the 60-tonne vessel offers the most efficient and effective vessel type from an operational viewpoint.

This figure's final result presents the vessel categories' payback period (PBP). The figure reveals that vessel category of up to 30 tonnes cannot pay back the investment cost. Meanwhile, the 60-tonne vessel has the lowest PBP with a repayment period of seven years. Based on all these analyses, it can be concluded that the 60-tonne vessel is the optimal vessel capacity for the barge owners from both investment and operational viewpoints. It also offers a competitive transport option for the shippers, as it offers a significantly low transport price that compensates for its high lead time compared to road transport. In line with this, the vessel design and operational profile of the 60-tonne can be discussed. More details of these are presented in the following subsection.

Figure 7.12: Length, PBP, and number of vessels needed



7.4.2 Vessel design and operational profile

It has been established from the previous analyses that the viable vessel capacity to use in the urban context is a 60-tonne vessel. Based on this, this part presents this vessel type's designs and discusses the vessel's logistics operational profile in the urban freight delivery context. Before this, however, the variables used in determining the vessel design are presented in Table 7.6. These variables include the cargo configurations, the deck configurations, and the cargo hold configuration.

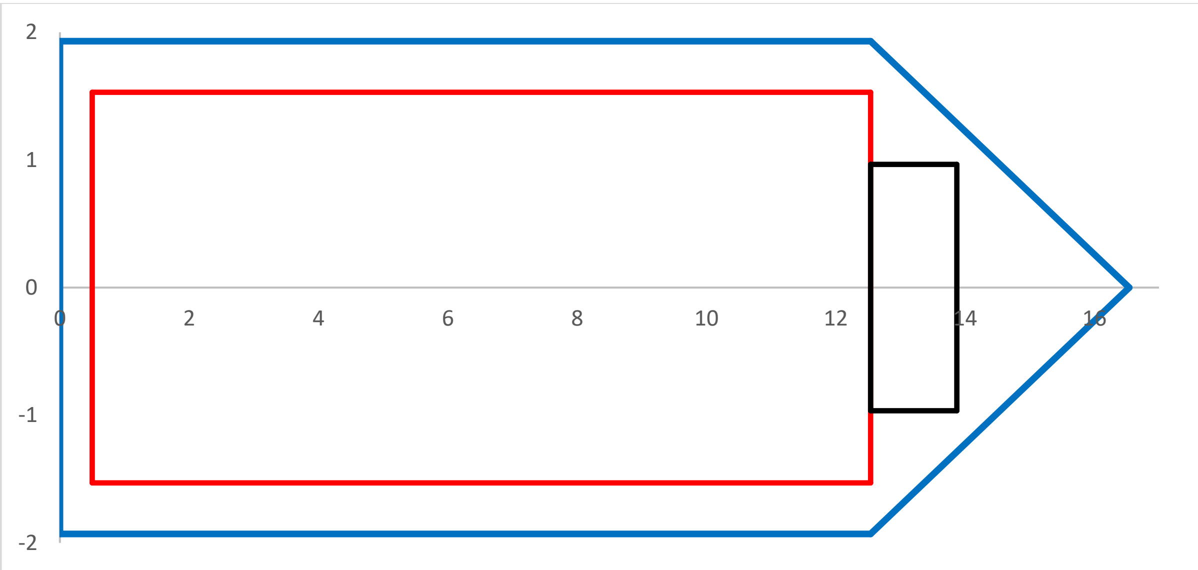
Table 7.6: Vessel design variables

Variable	Value	Unit
Width cargo	0.715	m
Length cargo	0.81	m
Height cargo	1.8	m
Avg. weight of cargo	1000	kg
Length forepeak	4	m
Length aft deck	0.5	m
Width side deck	0.4	m
Spacing cargo	0.05	m
Double bottom thickness	0.3	m
Height hold	2	m
Roof thickness	0.1	m
Freeboard	0.8	m

Table 7.6 reveals the assumptions specified for the vessel design specification. This specification is based on the technical assumptions by van Reeuwijk, (2022). Starting with the cargo specifications, the cargo's width, length, and height are defined as 0.715m, 0.81m, and 1.8m, respectively, whereas the average weight of the cargo is assumed to be 1 tonne per cargo, and a cargo spacing of 0.8m. The vessel is specified to have a forepeak length of 4 meters, an aft deck length of 0.5 meters, and a side deck of 0.4 meters wide. Furthermore, the vessel is estimated to have a double bottom that is 0.3 meters thick, a roof thickness of 0.1 meters, and a free board space of 0.8 meters. Finally, a height hold of 2 meters is estimated for the vessel.

Based on these, the vessel design can be specified. This is presented in Figure 7.13. The vessel's overall length (60-tonne capacity) is 16.54 meters from the figure. Meanwhile, the width and depth are calculated at 3.86 meters and 1 meter, respectively. Concerning the hull, the length of the hull is estimated at 12.54 meters. Regarding the cargo hold space, the cargo space length is 12.54 meters, while the width is estimated at 3.06 meters.

Figure 7.13: vessel design of a 60-tonne capacity



Based on this design, the operational profile of the vessels can be specified. This is presented in Table 7.7. As confirmed from the previous analysis, the capacity of the optimal vessel is 60 tonnes; however, with an assumption of a 90% occupation rate, the vessel has an estimated payload of 54 tonnes. The total hours spent per trip (sailing and handling) is calculated as 2.9 hours. Based on this and daily operational hours of 14 hours, it is estimated that the vessel can complete five trips per day, 30 trips per week, and 1,560 trips per year. With this information, two vessels with the same operational profile will be required to complete the annual transport of 200,000 tonnes. Regarding the power demand, the total power demand of 18,922 Kwh will be needed per vessel. With a specific fuel consumption (SFC) of 230, the total annual fuel consumption is calculated as 5,373 liters per vessel.

Table 7.7: Operational profile of the optimal vessel

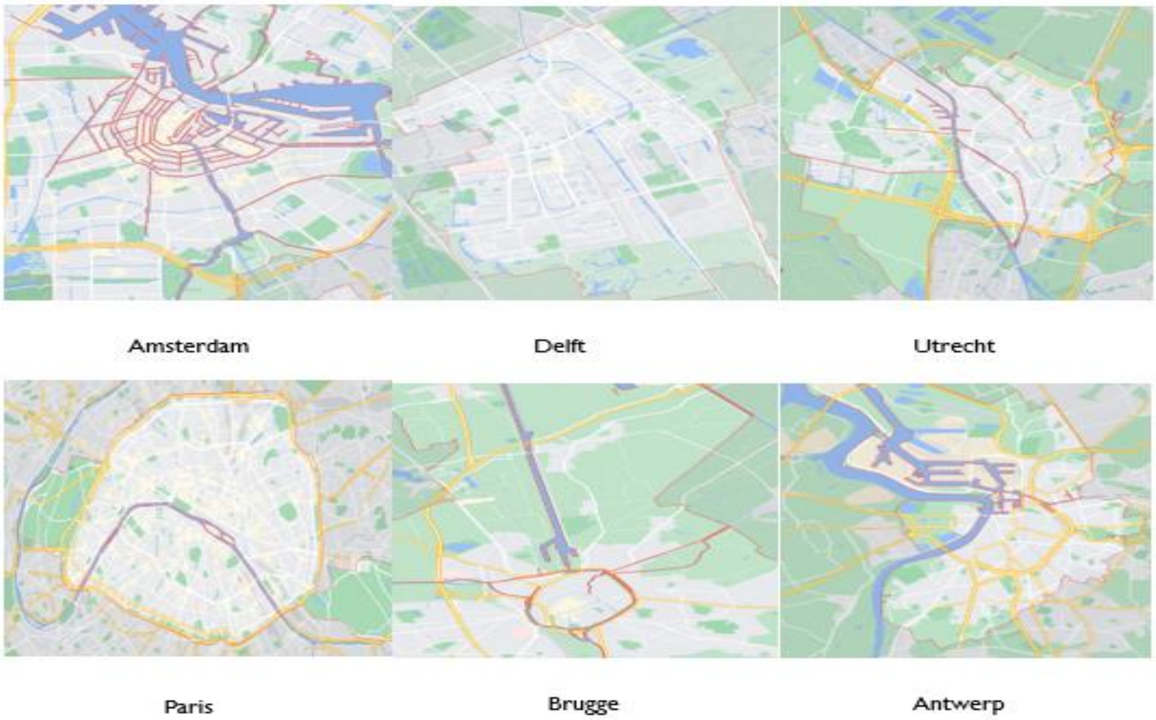
Element	Value	Unit
Payload	60	tonnes
Operational hour/year	4,546	hr
Payload carried/sailing	54	tonnes
Operational days in a week	6	days
Distance	6	km
No. of trips per year	1,560	-
no. of trips per week	30	-
No of trips per day	5	
Avg. Speed per trip	7	km/hr
Sailing hr (round trip)	1.7	hr
Total no. of hr	2.9	hr
Operational hours per day	14	hr
Number of vessels needed	2	-
Power demand cargo handling	4.5	kW
steering and maneuvering	2	kW
Max installed power	175	kW
Total power demand per year	18,922	Kwh
SFC	230	-
Fuel consumption	5,373	l/year

Having conducted the analyses on the potential of using small vessels for urban freight delivery in Ghent, the question now begs whether the same approach can be applied to other urban areas with small waterway connections within the city. This question is answered in the next section by looking at the generalization of the developed model to other urban areas.

7.5 Generalization to possible other application areas

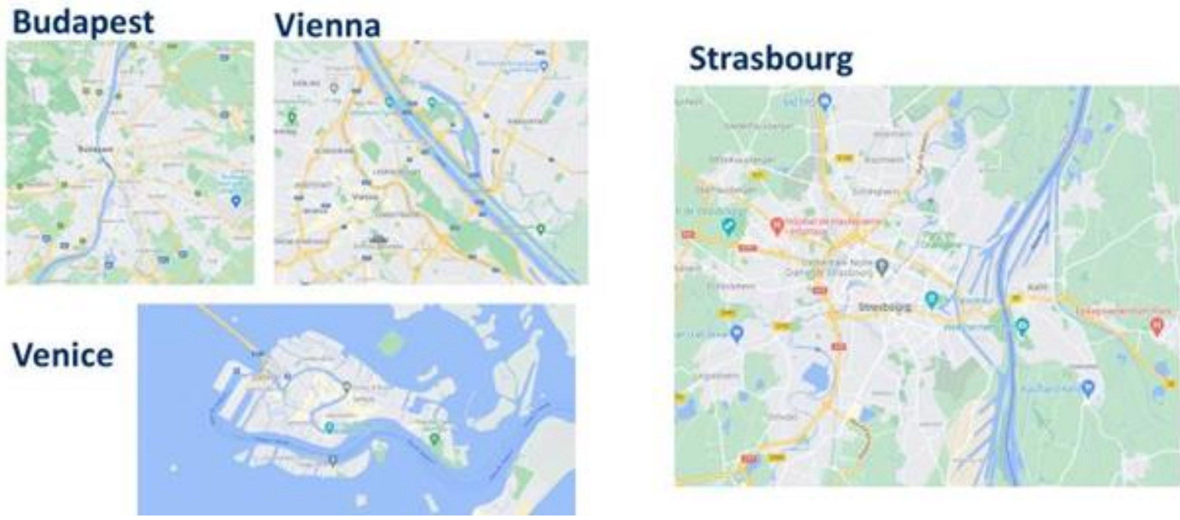
Although the scope of the previous analyses was limited to the city of Ghent in Belgium, the developed model has been designed to be used and generalized to other urban areas with small waterway connections. These urban areas include Amsterdam, Delft, Utrecht, Paris, Brugge, and Antwerp, to mention a few (Figure 7.14).

Figure 7.14: Other potential application areas



Other possible application cities include Budapest, Vienna, Venice, and Strasbourg (Figure 7.15). One common thing among these urban areas is the connectivity of small waterways to the city. This presents an opportunity to use an alternative transport mode (IWT) besides road transport.

Figure 7.15: Possible other application cities



However, before applying the PSB concept to a specific area, some area-specific assumptions should be reviewed for the urban area under study. The premises explicitly specified for the city of Ghent are such that the average speed of road transport is set at 30kph. This might be an underestimated value, especially considering that the transport activity would occur on express roads and regular roads within an urban area with a speed limit of between 50 and 70 kph, depending on the area. It might be interesting to see how the increase in truck speed would affect the dynamics of the TLC, especially in the private case. Secondly, the analysis assumes empty sailings (the vessel sails back empty). This might differ in other areas with opportunities to transport cargo in both directions.

Furthermore, the WACC value used is low. It could be that other areas use a high WACC rate which could affect the financial analysis of the cargo owners. Finally, the trajectory used in the case study covers a relatively short distance; other urban areas might have a longer trajectory for this operation. It will be interesting to see how the analysis dynamics change on longer transport distances.

Having generalized the model, it has to be determined how uncertainties and unknown futures could affect the established results. A changing future could affect the result in several ways. For instance, if the specified lifespan of the small vessels is more prolonged than initially assumed, the project's benefits could be greater than projected. Furthermore, an increase in the fuel price than what has been assumed could drive up the transport cost, which could affect the benefits of using small IWT. In addition, technological advances such as the development and deployment of drones could change how cargoes are transported to urban areas, affecting the future of urban IWT. A further example of technological impact could be technologies or processes that could further ease the transshipment and handling of these cargoes in urban areas. This would further reduce IWT cost and time, making IWT more attractive.

Another uncertainty could be the changes in urbanization patterns, such as population growth or shifts in the location of commercial areas. This could impact urban freight flow, thus affecting the viability of using urban IWT. A final uncertainty is the changing regulations on restrictions in cities and urban areas, which could affect the cost and efficiency of urban IWT.

In general, the impact of changing or unknown conditions on the results in this research will depend on some factors, including the type of goods being transported, the urban context in which the transport occurs, technological advancements, and the changing regulations.

7.6 Synopsis

The study examines the feasibility of using PSBs for urban freight delivery. In doing this, an SCBA analysis was performed. The analysis was performed from two viewpoints; the private viewpoint and the welfare viewpoint. The study examined two modes of transport (road and IWT). 16-tonne capacity was considered for road transport, while four different vessel categories were discussed for IWT transport (conventional PSB, conventional Zulu, autonomous PSB, and autonomous Zulu). Financial and total logistics cost analyses were performed from the private and welfare viewpoint to determine the concept's impact on the respective actors. Some insights can be deduced from these analyses.

Firstly, regarding the vessel type, PSBs (conventional and autonomous) appear feasible for the vessel owner both from the private and the welfare point of view. A possible reason for this is the short distance in the vessel trajectory from the pick-up to the drop-off point, making it more efficient and effective for the PSBs while being less efficient for the Zulus from both the operational and the financial perspective. Regarding the TLC, PSBs appear to be the cheapest option for low-value goods from the private point of view, while trucks remain the cheapest option for high-value goods. However, by internalizing the external costs, the PSBs offer the cheapest option for all categories of goods for the cargo owners from the welfare viewpoint. Furthermore, switching to PSB from trucks would yield an annual total external cost reduction of 76%, a net positive benefit to society. With this, the net benefit for all the actors appears to be favorable, justifying the use of PSBs.

Based on this, sensitivity analysis was conducted to determine the optimal vessel size from a scientific viewpoint. This analysis discovered that a 60-tonne vessel would be an optimal capacity for this type of operation. This results in a vessel design that is 16.54 meters long, 3.86 meters wide, and 1 meter deep. Finally, the model developed can be generalized to other urban areas with small waterway connections by adjusting some area-specific assumptions that are specified in the study.

Chapter 8 - Conclusions and recommendations

This last chapter presents the main findings of this research. Furthermore, the recommendations for future research are discussed. In line with this, section 8.1 briefly summarizes the research. Section 8.2 elaborates on the study's observations and main conclusions. Section 8.3 discusses the recommendations from the scientific, implementation, and policy viewpoints. Section 8.4 deals with the timing and future challenges of the analyzed innovations in this research. Finally, section 8.5 presents the research limitations and future research directions.

8.1 Brief summary of the study

Inland shipping could provide a competitive and more sustainable mode of transport in North-Western Europe, as it could take advantage of this region's large and dense inland waterway network. However, this has not been the case due to the different challenges faced in the container IWT sector. Furthermore, there have been growing concerns about the negative societal impact of road transport within dense cities and urban areas. This creates an opportunity for inland shipping to utilize the dense IWT networks that connect to the city centers to use last-mile transport to the urban areas. By doing this, inland shipping can offer a good alternative to road transport and take over some urban freight flows, enhancing its competitiveness and maximizing its underutilized capacities.

Based on this, this study examines how the current inland waterway transport market can be enhanced. This is done in two parts. The first part, which focuses on port-hinterland container transportation, is concerned with identifying the main challenges facing container barges in seaports: low priority, small call sizes, and poor handling of container barges. This study proposes a dedicated terminal space solution to address these challenges.

The second part, meanwhile, focuses on the possibility of using inland waterways for urban freight transport and whether this could serve as a better alternative to road transport. This part also examines the potential use case of using an automated vessel for this type of service and market.

Both parts were researched from an economic viewpoint using different methodologies and models to find potential solutions and positive business cases for the actors identified. The reason for using multiple methods in this research is that it enhances creativity in research design, which leads to new insights and perspectives that are not apparent through a single method. Based on this, two main objectives have been identified in the research. The first is to develop and analyze new approaches to improve the current port-hinterland container IWT logistics. The second is to examine the economic feasibility of using dense inland waterways for urban freight transportation.

These two main objectives are then reformulated into three main research questions:

1. What are the main challenges of container barge operations in seaports in North-Western Europe?
2. How can these challenges be addressed?
3. Is it possible to deploy (small) inland vessels for urban freight use from a private and welfare viewpoint?

To answer these questions, multiple methodologies were applied. For the first part, a quantitative survey was conducted to determine the practical challenges of container IWT in seaports. Results from the quantitative survey are then transformed into variables and parameters used to develop an Agent-

Based Model (ABM) to answer the first part of the second research question. The output of the ABM approach is analyzed in detail, and the suggested solution is further appraised using the economic assessment model. Regarding the second part (IWT urban freight transport), a social cost-benefit analysis (SCBA) is developed to answer the third research question.

These methodologies were applied to Europe's two largest container seaports (Antwerp and Rotterdam) and Ghent in Belgium. To ensure that the methods and models can be generalized, some transferability conditions were discussed to explain how and under which conditions the results can be generalized to other regions with inland waterway connectivity. Based on this, the following section presents each identified research question's main results and conclusions.

8.2 Observations and conclusions

This section describes the specific questions, summarizes the main results, and provides the main conclusions.

8.2.1 Identifying the main challenges of container barge operations in seaports

Improving IWT activities could serve as a mechanism to improve port performance and hinterland services, thereby increasing its attractiveness to shippers. To achieve this, collaboration and cooperation must be enhanced among stakeholders such as barge operators, terminal operators, sea carriers, shippers, freight forwarders, waterway managers, and the port authorities. However, this is currently not the case within the container IWT sector.

Different challenges have been identified in literature facing container barge transportation in Europe. However, to gain insights into the practical challenges and answer the first research question on the main challenges confronting container IWT, a survey was conducted among key actors in container IWT operation (shippers/forwarders, barge operators, and terminal operators. The purpose of the survey, among other things, was to understand the practical challenges facing container IWT from each actor's perspective and the competitiveness and prospect of container IWT within the different transport modes.

A general conclusion from the survey results revealed that the main challenges could be categorized into three main areas; handling, coordination, and flexibility. These three areas are further broken down into specific problems. These include the interference of deep-sea vessels, lack of dedicated barge spaces, small call sizes, poor planning, fixed slots, flexible schedules, and low service levels due to port congestion. While some of these problems are interrelated, such as dedicated barge space and deep-sea vessel interference (for example, creating a dedicated barge space would eliminate the issue of poor handling in sea terminals), others exist in isolation as individualism and personnel training. Further observation notes that while some problems could be addressed by innovation within the container IWT sector, others can only be addressed through a change in mentality within the industry.

Based on these insights, the thesis focused on problems that could be addressed via innovations within the sector with specific attention to issues like container barge handling in sea terminals, small call sizes, dedicated barge space, planning, and barge slots/scheduling in sea terminals.

8.2.2 How to solve these challenges

Having identified the main challenges in the first research question, this section then focuses on how to solve these challenges. This is done in two parts: the first part focuses on modeling barge congestion and handling in sea terminals. This is done by developing a system dynamic agent-based model to observe the evolution of barge congestion in seaports due to low priority, high waiting time, and poor handling. The second part then builds on the recommendation of the first part by conducting a detailed economic assessment of the potential solution recommended. This is done by developing time optimization and economic assessment models to determine the solution's logistics and economic feasibility.

Regarding the first part, which examines the handling and congestion of container barges in sea terminals, a base case and two alternative scenarios to resolve the challenges were identified. A system dynamic agent-based modeling was then developed to examine the three scenarios and determine the optimum scenario to reduce congestion and enhance barge handling.

A general conclusion from the analysis is that the combination of deep-sea vessels and the number of allocated cranes to the barges determine how long the container barges would wait at each terminal. This implies that not only do the container barges need dedicated spaces within each terminal, but they also need the appropriate number of smaller cranes that can efficiently handle them in the dedicated space; otherwise, the problem of congestion and handling would persist.

The analysis further revealed that the case with dedicated barge space offers the best solution to the congestion and handling issues. In this sense, if the terminals can create a dedicated handling space and invest in suitable infrastructures for the container barges, it could significantly reduce the waiting time of the barges and ensure that they do not spend an extended period at the terminals. With this, there could be a shorter lead time leading to more reliability and supply chain flow optimization.

However, as much as having a dedicated barge terminal leads to the optimal solution for the container barges, this does not mean they are economically viable for the actors involved. Based on this, there is a need to perform a detailed economic assessment of this solution to determine its viability for the respective actors. This is the aim of the second part, which focuses on the logistics and economic evaluation of having a dedicated space for cargo consolidation and handling.

Specifically, the second part examines how to resolve the current challenges by reducing port sailing and waiting times for barges through a dedicated barge space without expensive modifications to port infrastructures. A floating terminal concept called the Modular Mobile Terminal (MMT) is proposed to achieve this. An assessment methodology is developed to evaluate its potential operational efficiency for providing consolidation and distribution stations for container barge handling. A floating terminal was proposed considering the intensive land use in most ports.

The analysis conducted in this part demonstrates the economic potential of using the MMT as a potential solution for floating consolidation and dedicated handling space for container barges. An assessment methodology was proposed, where time savings optimization and cost estimation models were developed. In doing this, the proposed method combines logistics and economic aspects in a unified framework. It then provides insights into the MMT design, potential time and cost savings, operational constraints, and the market that can be targeted.

The proposed assessment methodology is applied to two ports (Rotterdam and Antwerp) and two cases (moderate seasonality and high seasonality scenarios). The overall conclusion of the analysis suggests that the MMTs are most suitable for regions and vessels with small cargo volumes and can deal with the effects of a high seasonality pattern (caused, for example, by a disruption). Regarding the specific ports, the analysis indicates that four MMTs would be optimal for the port of Rotterdam, while two MMTs would optimally be installed in Antwerp. Thus from the assumptions and available data, the concept can be seen as a viable solution from an economic viewpoint for consolidating and handling low container volumes.

8.2.3 Possibility of deploying small inland vessels for urban freight delivery

To answer the question of the possibility of using small inland vessels for urban freight delivery, exploratory research was first conducted to examine the problems associated with urban freight delivery via the traditional mode (trucks). For this, it was observed that using trucks for last-mile urban delivery leads to different societal and sustainability challenges such as congestion, emission, pollution, accidents, and infrastructural degradation.

To address these challenges, sustainable and efficient solutions must be examined to serve as an excellent alternative to the traditional transport mode (road transport) to urban areas. Based on this, the idea of reactivating the small inland waterways for urban freight delivery is discussed. To implement this, there is a need to develop small vessels that can sail along these waterways without restrictions. Although pilot projects have been conducted using small vessels for urban freight deliveries, little is known about this transport option's economic and societal impact on the actors involved. Based on this, it becomes important to develop a methodology that assesses the economic impact of this option from the private and welfare viewpoint.

Consequently, answering the associated research question was divided into two parts. First, a methodological framework was developed to identify and model the evaluation technique for each actor and determine the actors' decision criteria. The second step then applies this methodology to the specific cases to determine the economic feasibility of this transport option from both the private and welfare viewpoints.

For the first part, an SCBA was developed to consider the transport option's societal impact. In doing this, the main actors are identified and analyzed. Furthermore, the different possible outcomes and their decision criteria are stipulated. Based on this, the evaluation techniques to examine the project's feasibility for each actor are specified. This part also elaborates on the identified techniques by developing a model that calculates each evaluation technique and analyzes the decision criteria. In doing this, a cash flow model was developed for vessel owners, a TLC model was developed for cargo owners, and an external cost model was developed for society.

The second part then applies the SCBA model to the identified cases. The analysis was performed from two viewpoints; the private viewpoint and the welfare viewpoint. The analysis examined two modes of transport (road and IWT). 16-tonne capacity was considered for road transport, while four different vessel categories were discussed for IWT transport (conventional PSB, conventional Zulu, autonomous PSB, and autonomous Zulu). Financial and total logistics cost analyses were performed from the private and welfare viewpoint to determine the concept's impact on the respective actors.

Some insights were deduced from the analysis. Firstly, regarding the vessel type, PSBs (conventional and autonomous) appear feasible for the vessel owner both from the private and the welfare point of view. A possible reason for this is the short distance in the vessel trajectory from the pick-up to the drop-off point, making it more efficient and effective for the PSBs while being less efficient for the Zulus from both the operational and the financial perspective. Regarding the TLC, PSBs appear to be the cheapest option for low-value goods from the private point of view, while trucks remain the cheapest option for high-value goods. However, by internalizing the external costs, the PSBs offer the cheapest option for all categories of goods for the cargo owners from the welfare viewpoint.

Furthermore, switching to PSB from trucks would yield an annual total external cost reduction of 76%, a net positive benefit to society. With this, the net benefit for all the actors appears to be favorable, justifying the use of PSBs. Finally, based on this, sensitivity analysis was conducted to determine the optimal vessel size. This analysis discovered that a 60-tonne vessel would be an optimal capacity for this type of operation. This results in a vessel design that is 16.54 meters long, 3.86 meters wide, and 1 meter deep.

8.2.4 The overall conclusion of the research

Based on the answers to the research questions, some overall conclusions can be derived from this study. These overall conclusions suggest that although different challenges of container barges have been studied using different approaches, this research indicates that low priority and poor handling are the significant factors affecting container barge operations in sea terminals.

Furthermore, the research further indicates that the container IWT challenges are interrelated. However, this interrelation can be categorized into three main themes: handling, coordination, and flexibility.

The research further suggests that innovation or technological development cannot solve all container IWT challenges. While some challenges could be resolved by innovation within the sector, others can only be addressed through a change in mentality, market structure, and personnel training.

Additionally, The research indicates that having a dedicated terminal space for container barges would help resolve the main challenges they face in sea terminals (low priority and poor handling). Analysis conducted in this study reveals that a dedicated terminal space is feasible for actors from both economic and operational viewpoints.

Furthermore, regarding the dedicated terminal space, analysis conducted in this study suggests that this solution is suitable mainly for regions and vessels with small cargo volumes and that they can deal with the effects of a high seasonality pattern (caused, for example, by a disruption). Hence, vessels with high cargo loads or regions with high cargo volumes are better off sailing directly to and using the sea terminals. Based on this, a new market and business model could be developed to handle and consolidate small cargo volumes.

Subsequently, based on the economic possibility of using small vessels for urban freight transport. The analysis indicates that this could be a better alternative to road transport. Based on this, a new market could be developed for transporting low-time-sensitive cargo to cities. Research indicates that this is economically feasible from the financial and logistics viewpoint and could also help reduce the number of trucks entering the cities, thereby reducing the overall negative societal impact of urban freight via road transport.

Finally, sensitivity analysis results indicate that the optimal vessel capacity for this type of transport is a 60-tonne vessel with a design length of 16.54 meters, a width of 3.86 meters, and a depth of 1 meter.

This design specification would take advantage of maximizing economies of scale while escaping any sailing restrictions in small waterways. This way, the shippers can enjoy a low transport cost, while the vessel owners can also maximize their revenues.

8.3 Recommendations

Based on the observations from the analyses, some recommendations can be proposed in this thesis. These recommendations are divided into three parts: scientific, policy, and implementation. Each of these is further elaborated in the following sub-sections.

8.3.1 Scientific recommendations

Based on the performed research, some scientific recommendations have been formulated. Firstly, there is a low turnout of respondents to questions related to container IWT challenges. Future research can capture a wide range of respondents to get a comprehensive response to the main challenges. This would help validate and confirm the survey outcome in this study and solidify the main challenges facing container barges in seaports.

Secondly, although the ABM model developed does well in analyzing the congestion situation of the three scenarios, the model only considers how priority levels affect barge build-up and waiting. It does not consider the technical and operational details of the deep-sea and barges. Also, the ABM model does not observe the handling details and slot bookings. Based on this, future research might consider incorporating these technical details in future ABM models. This would allow for a detailed observation of the operational issues (such as planning, crane, and gang allocations) affecting barge build-up and waiting time in seaports from the practical viewpoint and not only from the priority viewpoint.

Furthermore, the ABM model simplifies the interactions between the agents (terminals, sea vessels, and container barges). In reality, these interactions are much more complex among the agents. Future research can consider the detailed interactions among agents within the ABM model.

Additionally, the input parameters and assumptions made in the ABM model are based on averages and static values from the specific terminal and barge operators. This was done for simplification purposes. This can be improved by including varieties of vessel and barge classes with their different specifications within the model.

Regarding the MMTs, critical assumptions in the model specify that inland vessels have an average waiting time of four hours at each sea terminal. In contrast, the shuttle modules do not experience delays at the sea terminals. These assumptions are static irrespective of the season or the time of day/week. Future research could therefore make these assumptions more dynamic by adjusting these values depending on the seasonality, the demand, and the terminal schedules/planning (how busy the terminal is). In this way, the real impact of the dedicated barge space on barge congestion and waiting time can be realized.

Subsequently, regarding the potential of small vessels for urban freight use, the study assumes a filling rate of 90% for the vessels. This might be overestimated; hence, future research might consider the dynamic nature of this by determining the filling rate of the vessel based on the cargo flow of the goods to the city and the daily transport demand.

8.3.2 Implementation recommendations

In addition to the scientific recommendations, five implementation recommendations are also suggested from the analysis conducted in this research. Firstly, regarding the MMTs, investors should make strategic decisions on the number of MMTs that can be invested in and deployed. Although the analysis indicates a definite number for the port of Antwerp and Rotterdam, it is suggested that the investment company can conduct its separate analysis with the same model but with specific assumptions and data. This would provide a more detailed and customized result for the organization that would be investing. Nevertheless, the analysis suggests that initial investment should be made on a small scale level to observe the evolution of its success and growth. Further MMTs can then be added depending on the concept's practical and economic success, cargo growth, and attractiveness.

Secondly, practical consideration should be given to the relationship between the potential investors in the MMTs and the terminal operators. Based on the assumptions taken within the model that the shuttle transports have no waiting time at the sea terminals, it is therefore important to have a working relationship between the MMTs and the terminals where the shuttle transport can get a fixed slot at the terminal. Based on this, the study suggests that the sea terminals could take up the MMTs concept.

Furthermore, based on the analysis, a niche market of vessels handling low cargo volumes is recommended to be targeted by the MMTs. This type of market yields the most profitable business case for MMTs. However, investors can also generalize the developed model to other business cases using their specific data and assumptions to determine the feasibility of different business cases.

Regarding urban freight transport via IWT, a practical consideration for urban freight IWT is identifying the priority of the target shippers when transporting the cargo to urban areas. Do they give high priority to low transport/lead time and less emphasis on the transport cost? If this is the case, urban IWT transport might not be as competitive as suggested in the analysis. Based on this, the study advises conducting a pilot study with low-time-sensitive goods/low-value goods to determine the acceptance level and the practical usage of these barges.

Finally, suppose a high acceptance rate with the low-value cargoes; the solution can then be extended to other cargo types that can be palletized. This will increase the mode share of urban IWT for palletized cargoes, thereby reducing the average transport costs.

8.3.3 Policy recommendations

Based on the above recommendations, six policy recommendations can be identified. Firstly, as the analysis indicates that a floating terminal is possible from operational and logistical viewpoints in seaports, the port should put effort into ensuring the implementation and market uptake of this concept by companies within the port. This can be achieved by organizing a pilot study to determine the practicalities of the concept in the port area. If this is successful, investors can be invited to invest and commercialize the concept. In conducting the pilot study, attention should be given to the location, working requirements, and safety to ensure the concept does not interfere with or disrupt other activities/vessels within the port area.

Secondly, to ensure the implementation of the MMTs in the port, it is important to provide a start-up subsidy or a low-interest loan guarantee fund, which could motivate investors to implement this concept. This subsidy should only cover the implementation of the system and not the actual operation. It should only be given to investors that can guarantee a certain level of relationships with sea terminals, such as guaranteed fixed slots, dedicated cranes, and no/little waiting time for the shuttle barges. In addition to this, the business model should demonstrate a sustainable cash flow over time and guarantee that it should be able to compete without the help of government subsidies over a given period.

Furthermore, regarding urban freight IWT, the study has demonstrated that not only it is possible and feasible to use small vessels for urban freight delivery, but there is also a potential for using an autonomous vessel for this type of operation. Based on this, the policymakers could help by fostering the further use of advanced autonomous technologies in small vessels. This can be done by funding pilot studies of autonomous sailing and providing funds for technological research into small autonomous vessels. The insights from this study indicate that having small autonomous vessels that can sail independently and be controlled from the onshore facility would mean that a single captain could control multiple vessels simultaneously. Successful implementation of this possibility would solve two main issues. First, it would resolve the shortage of personnel members for inland navigation as fewer personnel would be needed for more vessel operations. Secondly, implementing this option would further decrease the transportation costs for the small-barge system, consistently increasing the profitability and competitiveness of this concept. This would lead to a positive business case, making it more attractive for investment companies and banks.

In addition to the above recommendation, the successful implementation of the small urban freight vessels requires upgrading the small waterway infrastructures. This can be done by installing sensors, cameras, and communication channels along the waterway infrastructure. This would not only help the smooth installation of the necessary technologies along the waterway but also make handling and accessibility of the cargo easier for the shippers. This would, in turn, attract more cargo, thereby increasing the cargo volumes of the vessels.

Finally, the analysis indicates that using small vessels for urban freight delivery could lead to an annual external cost reduction of up to 76% compared to using trucks, making this a more sustainable option for transporting cargo to urban areas. Based on this, policymakers could create an incentive in the form of subsidies or compensation for shippers to encourage them to think more about using this option when considering their transport options for urban freight delivery.

In addition to the above, policymakers could implement a pricing strategy for the transport modes that capture the internalization of external costs. This would make road transport more expensive as it has a higher negative externality than rail or IWT, making urban IWT a more attractive option for shippers looking for a low transport option to urban areas.

8.4 Timing and future challenges of analyzed innovations

The dedicated barge (MMTs) solution for port-barge operations and the small vessels for urban freight solution analyzed in this thesis face some challenges related to the timing of implementation and future issues that might arise during its implementation. Firstly, the long development and implementation period of the concepts. This is due to the significant investment required for this type of project. The long development period could cause delays in the implementation of new technologies, thereby making it difficult for companies to adapt quickly and be flexible to changing market conditions.

Another challenge for the analyzed innovations is the market's acceptability and adoption of the concept. The adoption rate of the concepts depends on the resistance level of stakeholders to changes and disruption of the existing system. The IWT sector can resist changes in the status quo, which can seriously challenge the analyzed concepts for market uptake and adoption.

A third challenge is the regulatory and legal issues, such as obtaining the required permits and complying with safety and environmental standards. All of these could lead to increase costs, thereby affecting the implementation of the innovations.

Finally, the uncertain future of container IWT poses another challenge to innovations. This is caused by climate change impact, changing trade volumes and flows, and shifts in consumer behavior. All of these bring some opportunities and threats to the success of the innovations. Hence, the need for innovations to be flexible to adapt to the changing market conditions to remain relevant and competitive.

These challenges require stakeholders within the IWT sector to collaborate to develop and implement the innovations. This collaboration requires investment in research and development, infrastructural upgrades, improvement of the current regulatory framework, and promoting the market acceptance and adoption of new technologies and processes. Doing this would make IWT more efficient, sustainable, flexible, and competitive in handling present and future demand.

8.5 Research limitation and future research direction

This doctoral thesis has demonstrated the economic feasibility of using a dedicated barge space to solve the main container barge challenges of congestion and handling. It has also shown the potential of using small vessels as a better alternative to road transport for urban freight delivery. However, some limitations in this research should be considered and could lead to future research directions.

Firstly, from the ABM modeling viewpoint, the model uses a static value regarding the vessel and barge size for simplicity. These static values provide the first insight into the congestion levels. It would be more interesting to make the model more dynamic by considering different vessel and barge sizes and what role the seasonality factor plays within the model. This way, the evolution of the congestion level can be followed in detail based on the class of the vessel, the economic situation, and the seasonal period.

Secondly, the assumptions in the study have been reasonably used to represent practical situations of the MMTs. However, more detailed research should be conducted based on more data to generate a more accurate result for practical implementation. In particular, regional flows are used, but a study at the vessel level could provide more information, as the MMT operations could be simulated with a higher level of detail. For example, a queueing model could be introduced to accurately infer the vessels' waiting times at the MMTs and sea terminals. The shuttles and sea terminals could also be explicitly modeled; thus, every shuttle could be assigned to a specific sea terminal.

Furthermore, regarding the demand, an uneven split of containers between the sea terminals should be considered as it would be more realistic, and the different inland waterway vessel types could also be represented. This would help to get a more detailed idea of the market to target. Nevertheless, the present study is essential as it provides primary answers and makes the first step toward more detailed models.

Fourthly, regarding the urban freight delivery part, the specified vehicle speed for road transport might have been overestimated, especially considering that the transport activity would occur on express roads and regular roads within an urban area with many build-up areas. Hence a limitation in the maximum vehicle speed by law needs to be introduced in the model. Also, there is a lot of congestion within an urban area which might further reduce the speed of vehicles.

Additionally, the analysis assumes that there are no empty sailings for PSBs. This might not be the case in practice, hence the need to perform a more detailed analysis of the urban cargo flow of PSBs and its subsequent effect. In addition, it might also be interesting to examine how increasing the vessel speed would affect the cost and operational implications of the vessels. This might be necessary, especially given the low speed of 4kph assumed in the analysis.

Finally, the WACC parameter used in the analysis might have been underestimated. Increasing this value would have an impact on the cash flow and NPV of the investment. It remains to be seen how significant the effect of an increase in the WACC would have on the profitability of the investment and at which WACC threshold the investment would stop being profitable.

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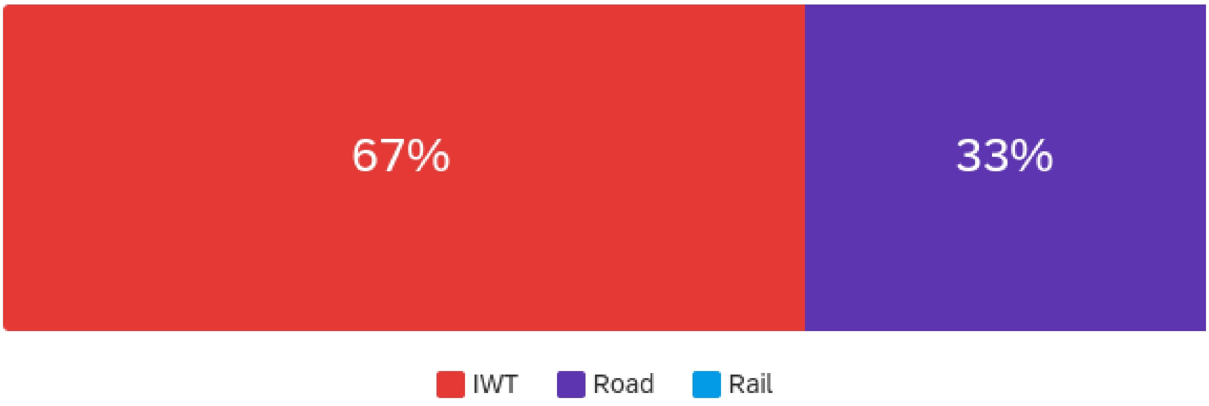
Appendix A

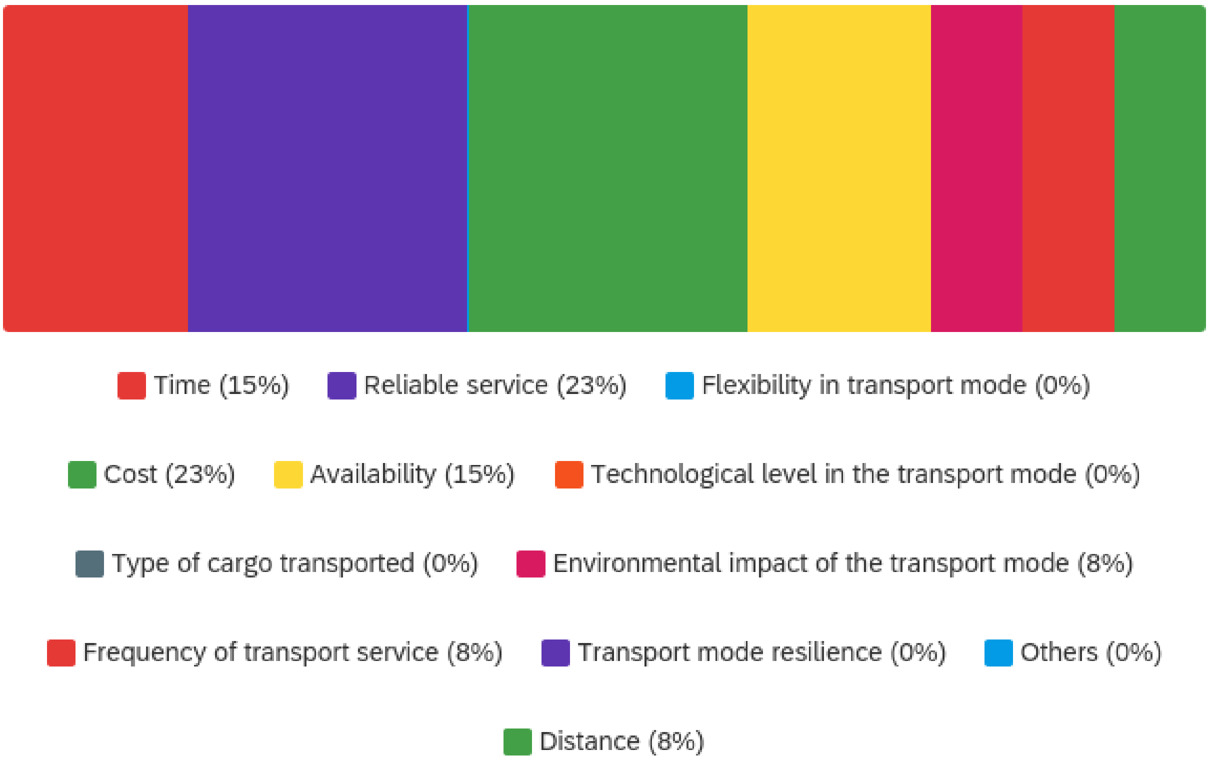
Survey report for shippers/forwarders

For the survey on shippers/forwarders, six reactions were received. The report of these reactions is displayed below:

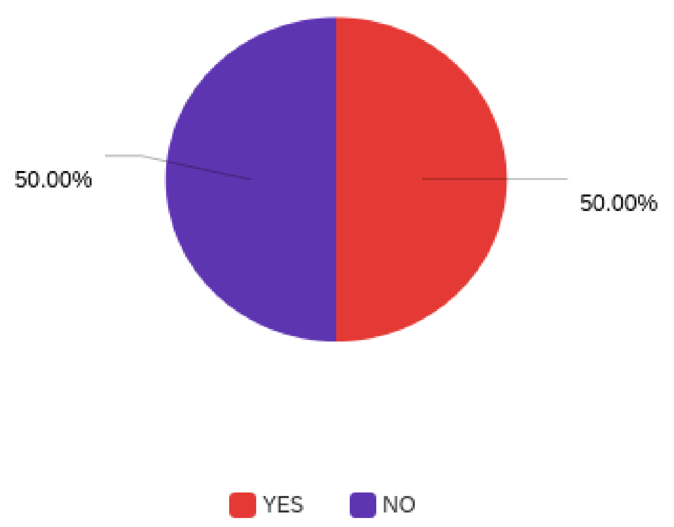
1. **What is your preferred mode for container freight transport?**



2. **What factors are important to you when making modal choices?**



3. Is IWT your first choice when making transport decisions?



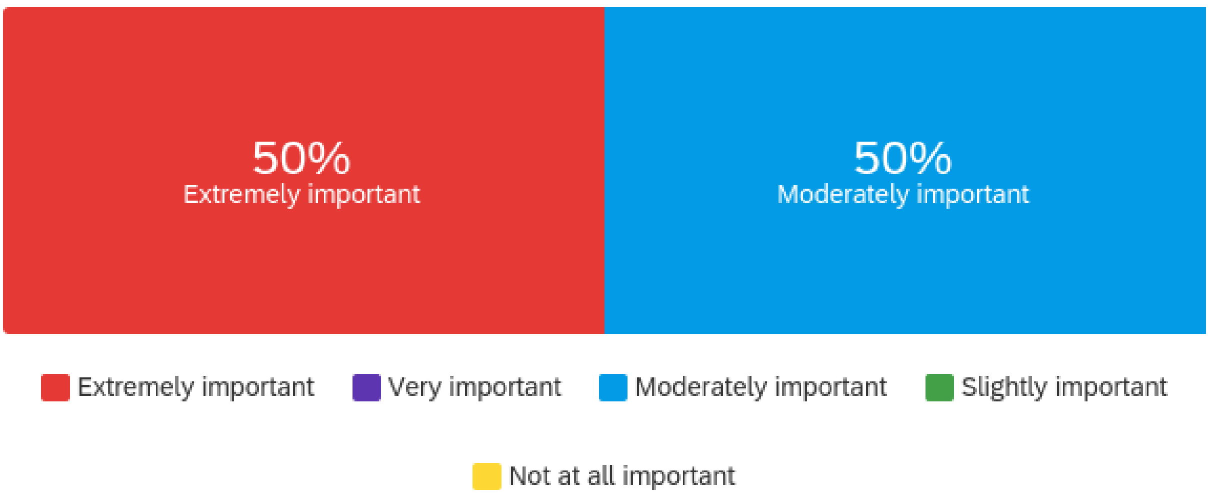
Reason(s) why IWT is the first choice when making transport decisions

- It is cost-efficient and environmental friendly.

Reason(s) why IWT is not the first choice when making transport decisions

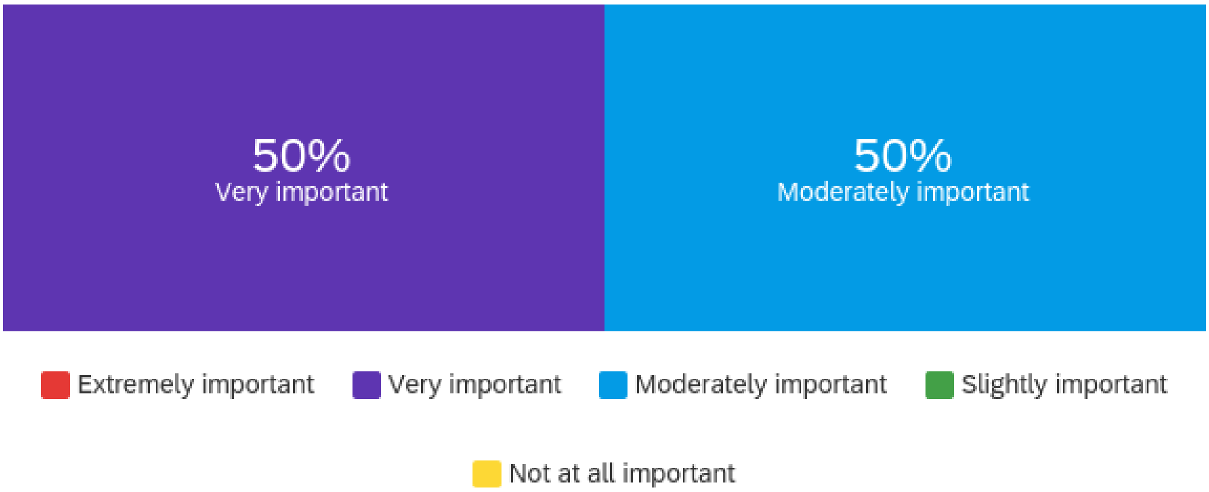
- It is unreliable
- It is not easy to use
- Lack of transparency in the sector

4. How important is "TIME" to you when making transport decisions?

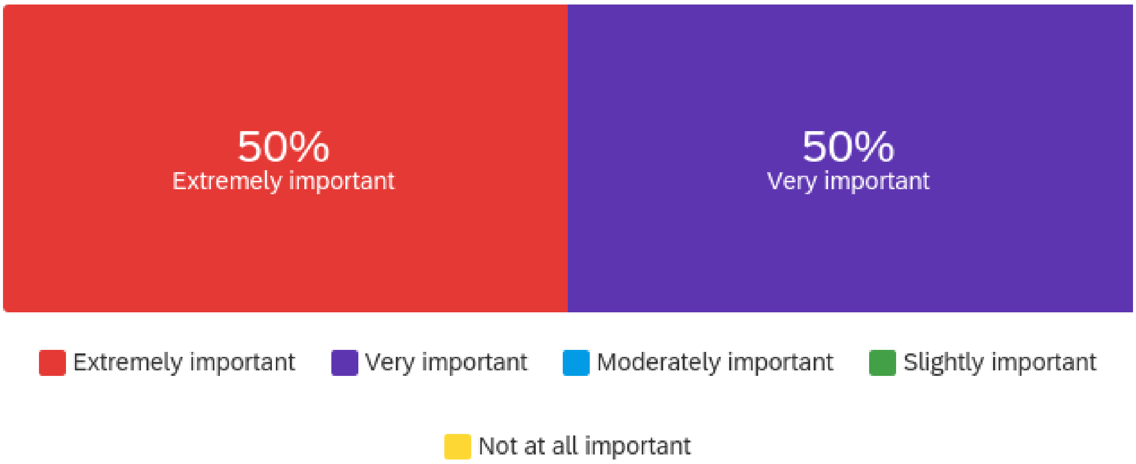


5. **How important is "RELIABLE SERVICE" in transport mode to you when making transport decisions?**

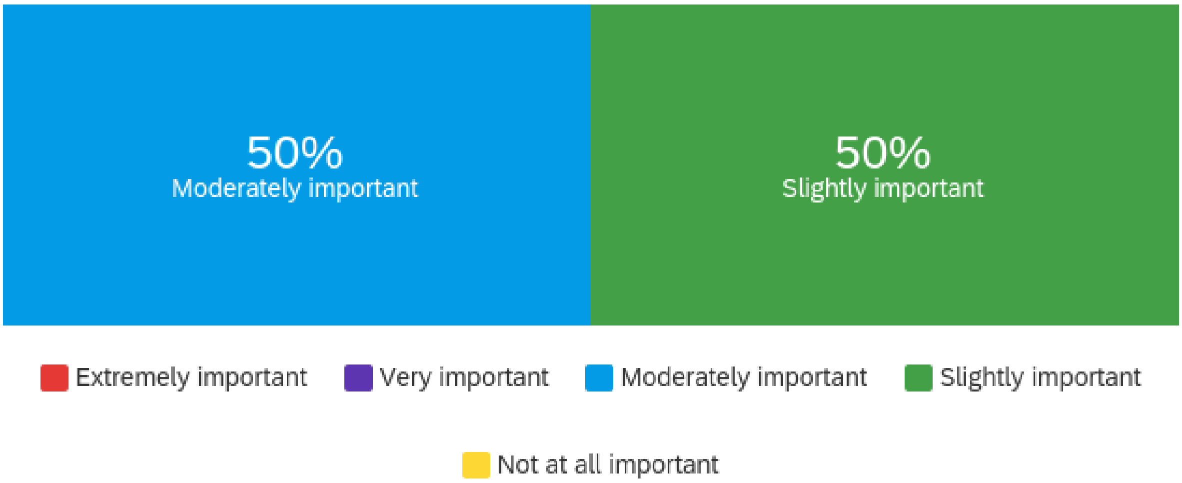
6. **How important is "FLEXIBILITY" in transport mode to you when making transport decisions?**



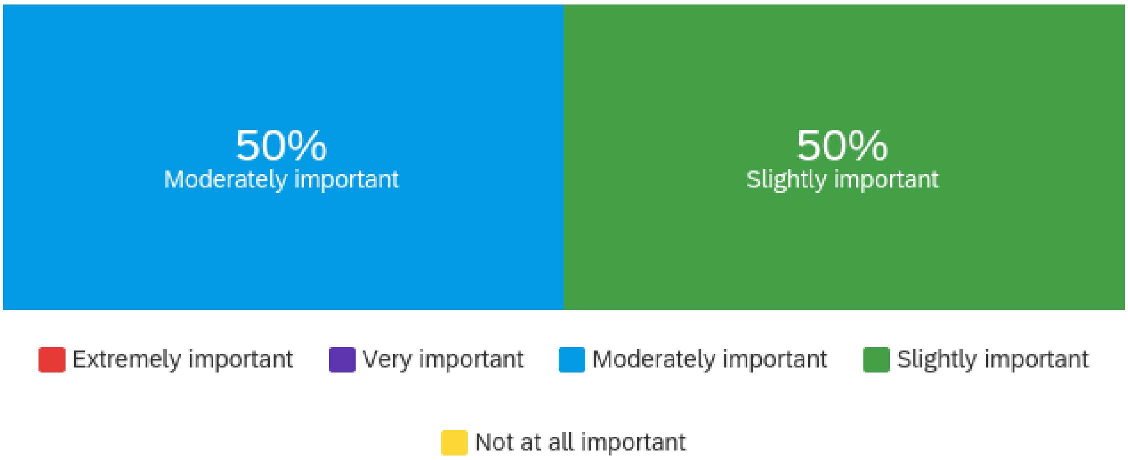
7. **How important is "AVAILABILITY" in transport mode to you when making transport decisions?**



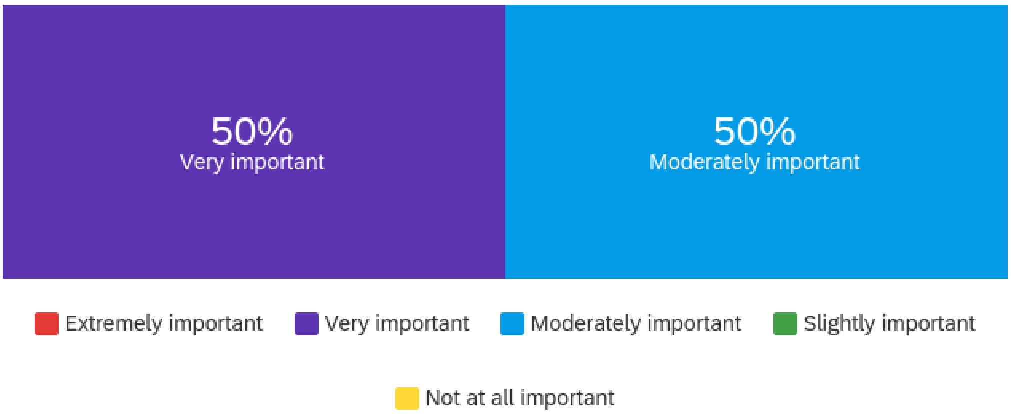
8. **How important is the "TECHNOLOGICAL LEVEL" in transport mode to you when making transport decisions?**



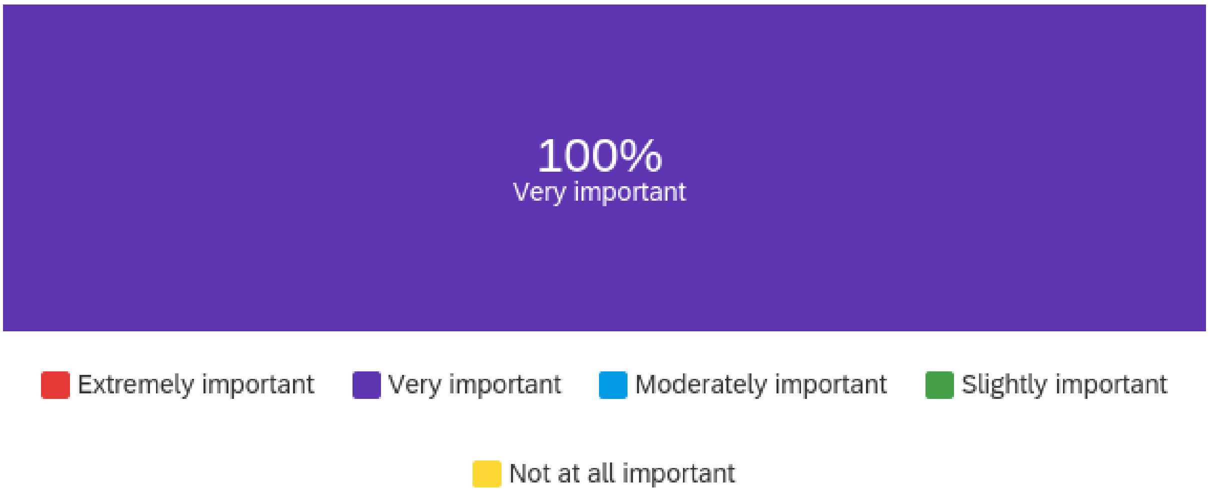
9. **How important is "CARGO SENSITIVITY" in transport mode to you when making transport decisions?**



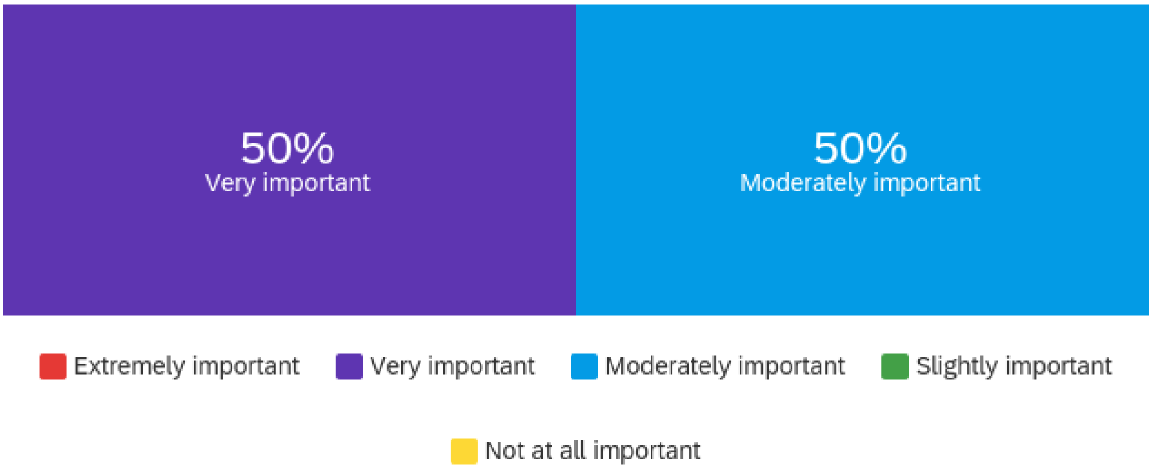
10. **How important is "ENVIRONMENTAL IMPACT" in transport mode to you when making transport decisions?**



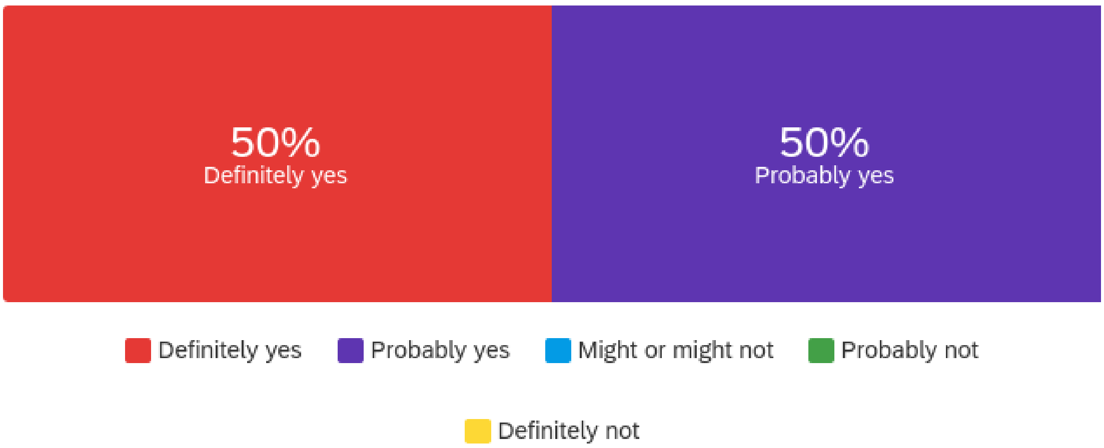
11. **How important is the "FREQUENCY OF SERVICE" in transport mode to you when making transport decisions?**



12. **How important is "RESILIENCE" in the transport mode to you when making transport decisions?**

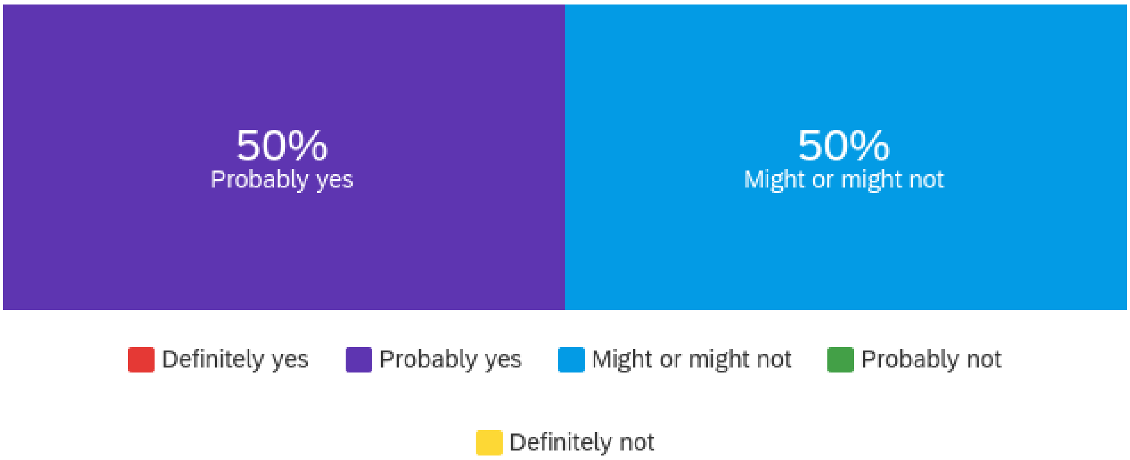


13. **Would you consider using more of IWT if it is more reliable?**



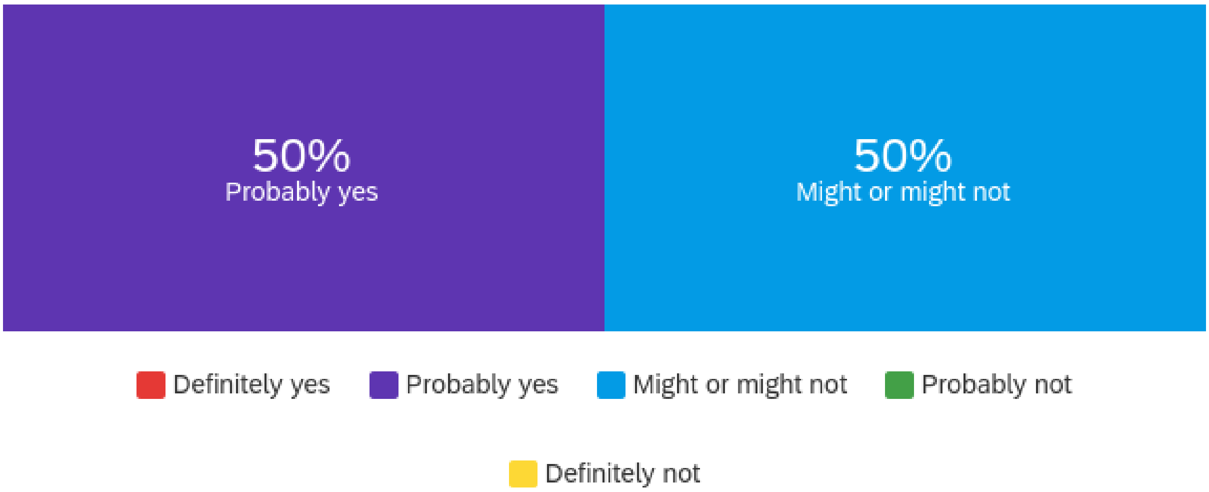
14. **Would you consider using more of IWT if it has a shorter lead time?**

15. **Would you consider using more of IWT if it is more flexible?**

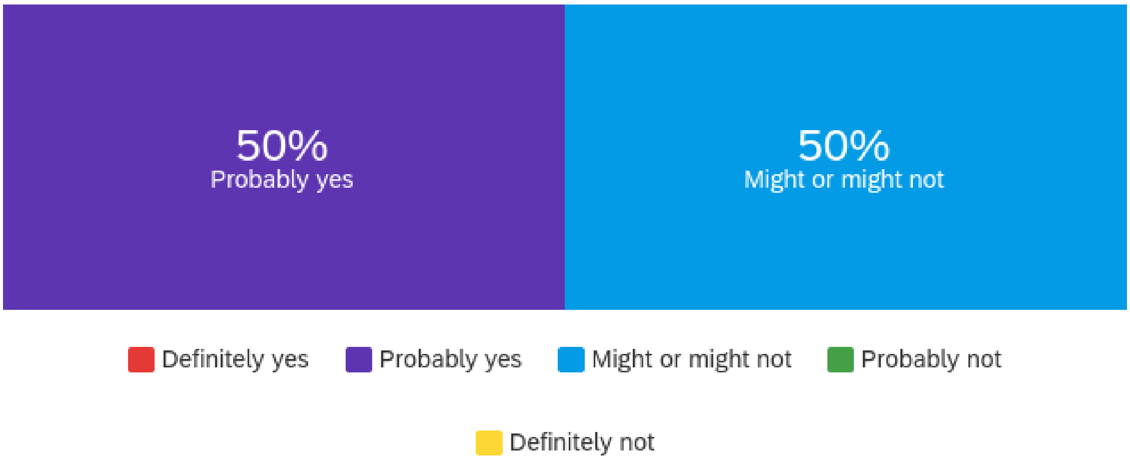


16. **Would you consider using more of IWT if it has a higher frequency of service?**

17. **Would you consider using more of IWT if there are more innovation and technological improvement in the mode?**



18. In your opinion, what other new or improved capabilities would make you consider more use of IWT for container freight transport?

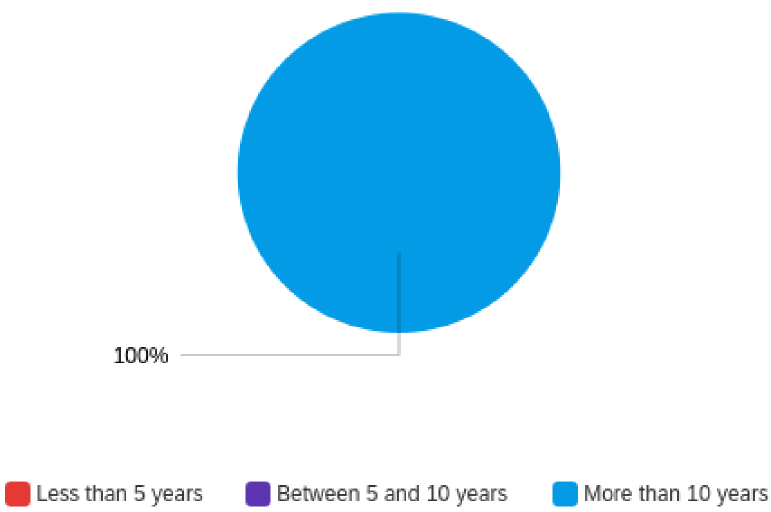


Appendix B

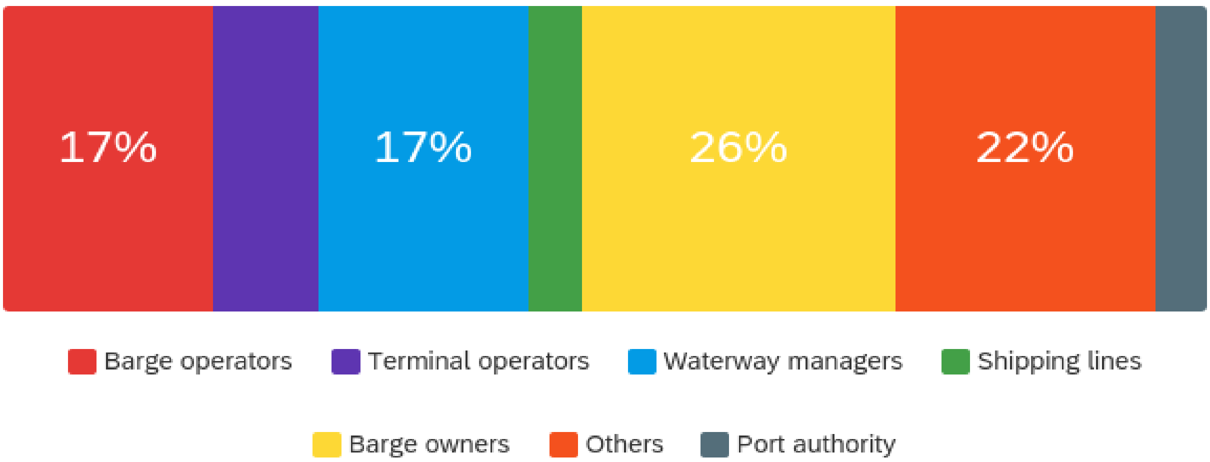
Survey report for container barge operators

24 reactions were received from barge operators on the survey regarding barge operations. The report of their responses is displayed below.

1. **Years of experience in the transport and logistics sector?**



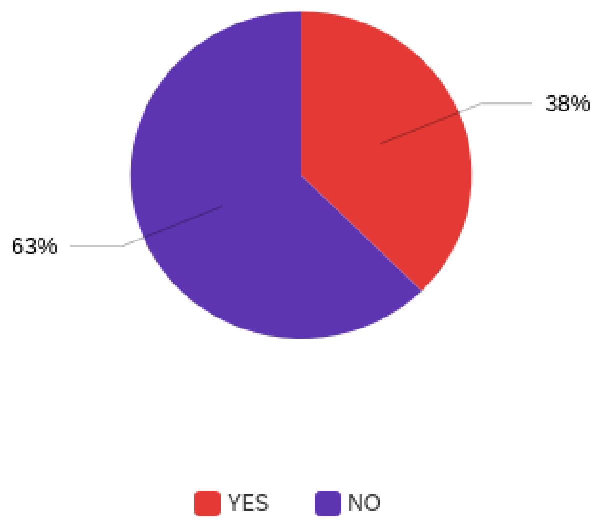
2. **Who in your opinion are the major players in inland container barge operations?**



Others include;

1. Shippers/Freight forwarders
2. Large companies and brokers
3. Service providers

3. Do these players share information among them? (available network or communication channels among the players)



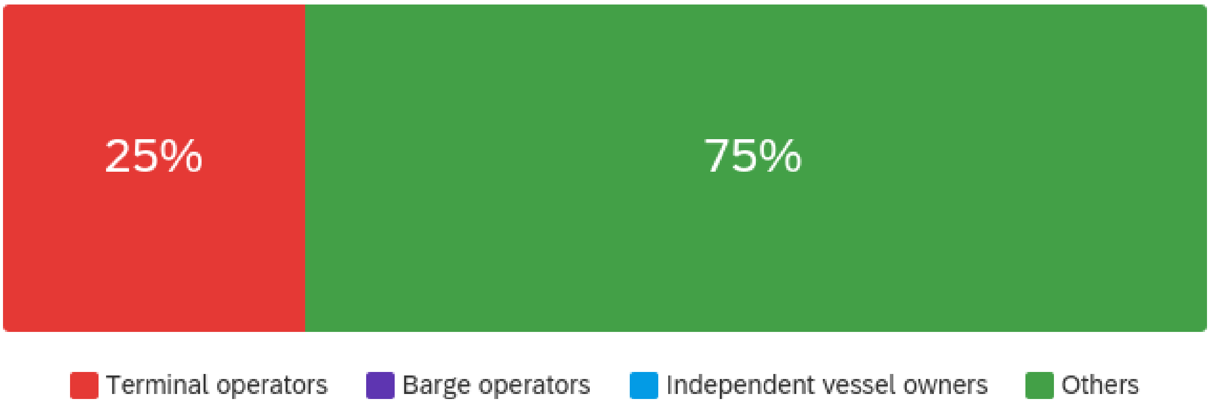
The type of information shared (for responses with yes)

1. All the necessary information.
2. Supply and demand for inland waterway transport and free capacities.
3. What is shared is strongly dependent on the relationship between the parties. There is usually little information between the terminal operator and the (representative of the) ships.

Why do they not share information (for responses with no)

1. Too much self-centred.
2. In the nautical field, there is plenty of information shared, however on a financial level everyone is busy with their financial gains.
3. They share information, however the information shared is not enough.

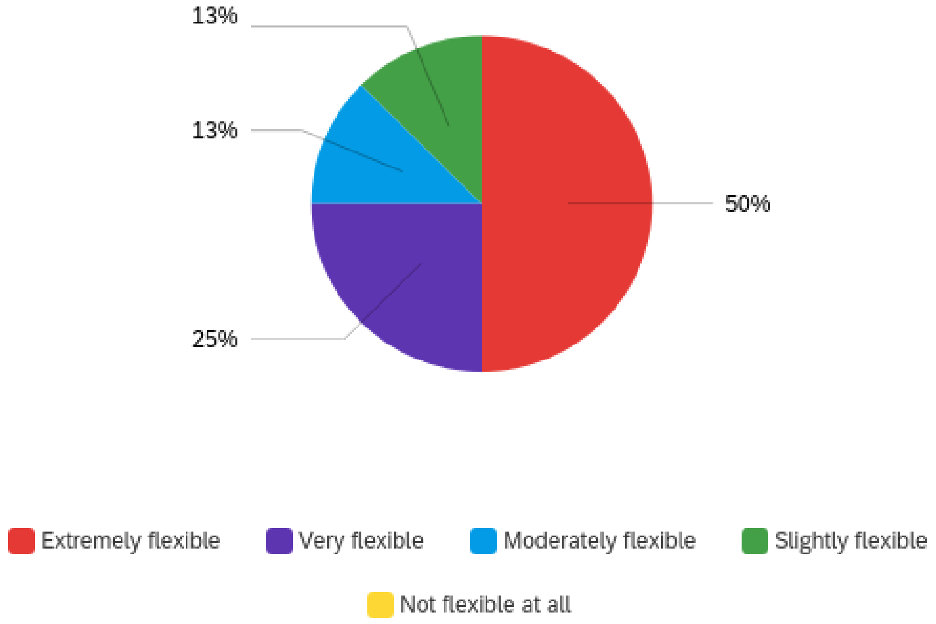
4. Who decides on the planning and organization of container barge operations?



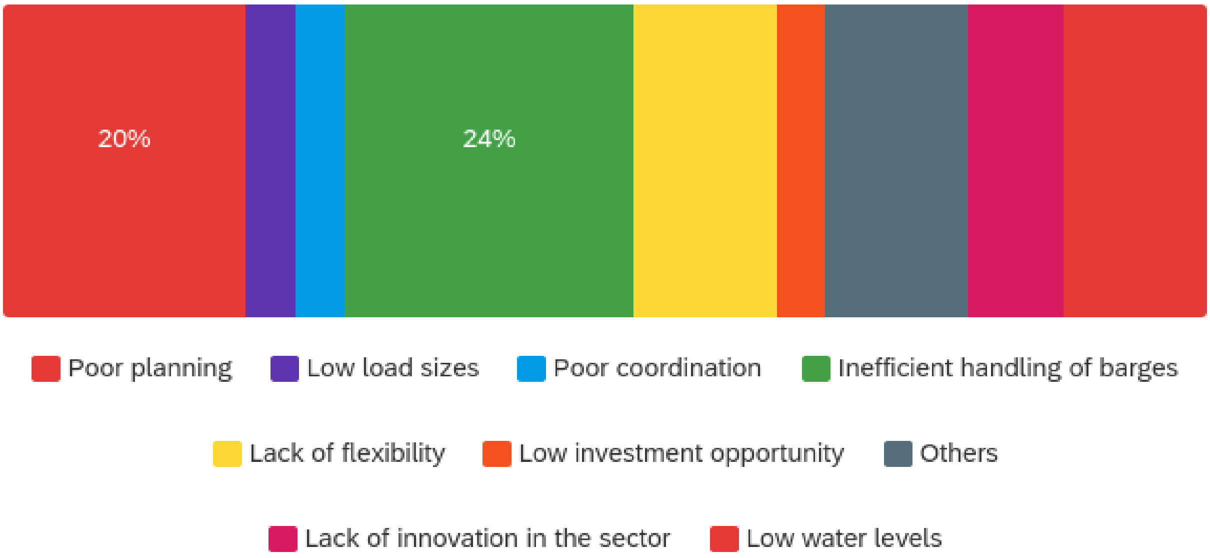
Others include;

1. Shipping companies/shippers.
2. Container operators
3. Deep-sea and inland terminal operators.

5. How flexible is container barge operations?



6. **In your opinion, what do you find to be the current challenges facing container barge operations?**

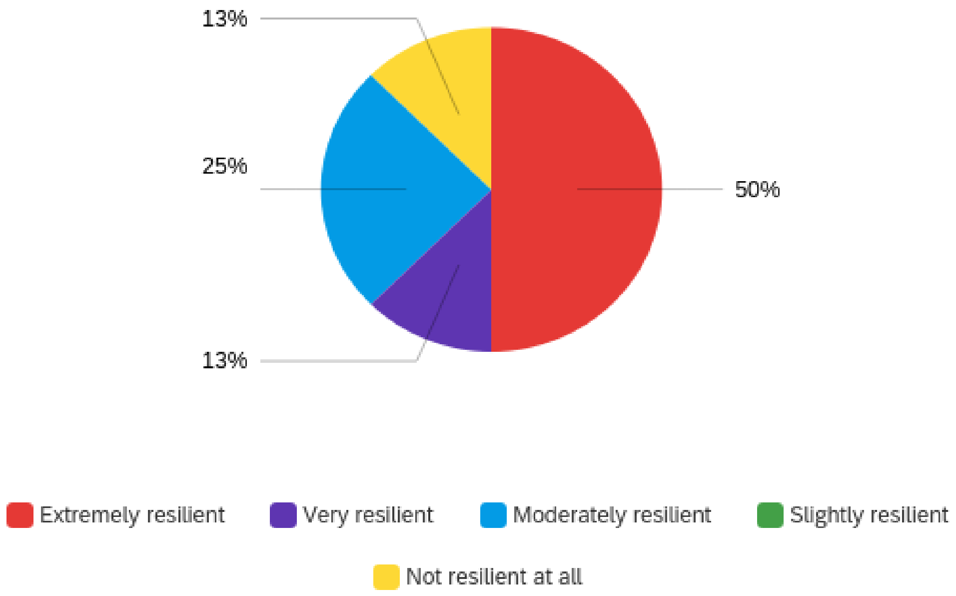


According to the survey, other challenges include;

1. Too low a reward for intensive work is disastrous. There can be no investment, no modernization; personnel cannot be paid after their hard physical labor.
2. The issue of sustainability in the sector. Don't build new container ships right now just because they can take a few TEUs more with them. There are too many dry cargo ships at the moment. This hurts the freight price. At the moment, many inland shipping companies are not satisfied. A solution for this is to develop a cleaner inland shipping sector by motorizing existing ships. This will be more sustainable and also cheaper.
3. Several links in the chain could also be removed. Now, too many intermediaries want to earn something from inland shipping. The money that is freed up can be divided between the customer, transshipment companies, and transporters. The price is now being cut, and the carrier often has to collect that money. So take a look at the chain and which links could be removed.
4. Due to the Rhine's changing water levels, regular ships must be hired to transport the containers. This does not benefit the price per TEU. However, I find that there is little flexibility in planning ships. One could plan ships flexibly by looking at the planning of ships differently. E.g. not always does ship A has to sail a round of Basel in 10 days, but perhaps ship B should sail one round and ship A to a different destination. That only requires more planning work for the container operators.

7. **On a scale of 1-5 to what extent will these innovations make IWT more attractive for container transport?**

8. In your opinion, how resilient are container barge operations?



9. What are the factors that could make container barge operations more resilient?

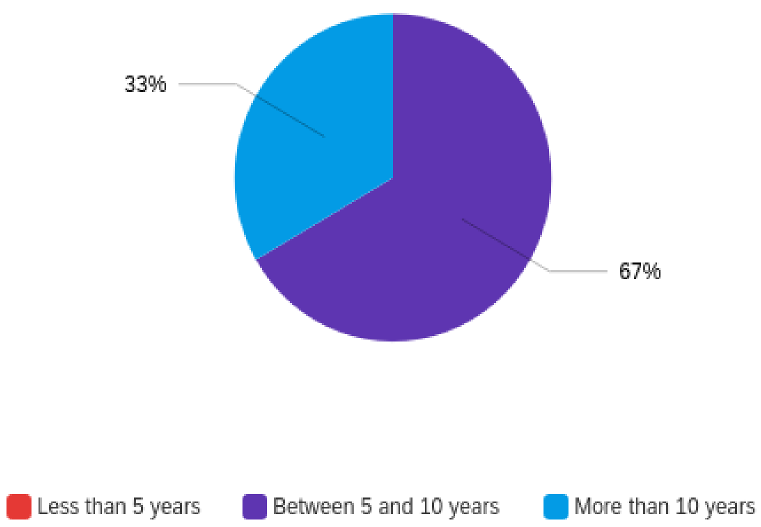
- Better coordination of operators (inland shipping companies).
- sufficient water levels
- Fixed slots for container barges in ports
- Splitting of cargo spaces
- Personnel training

Appendix C

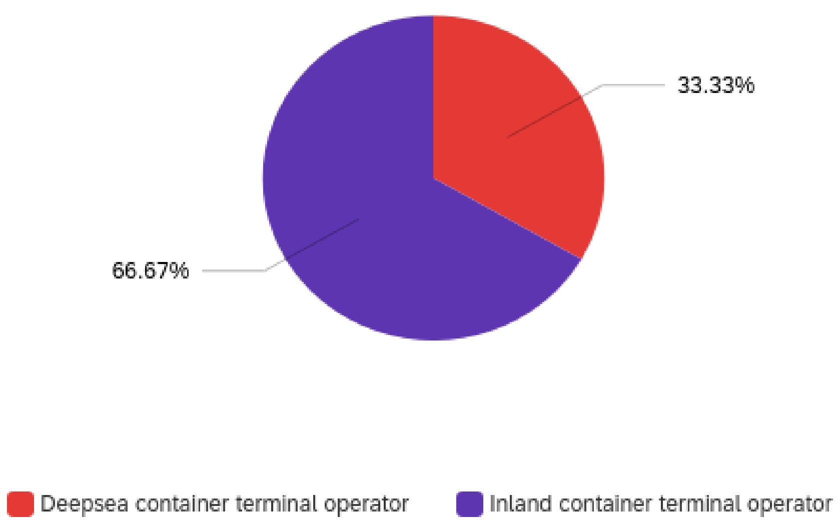
Survey report for terminal operators

Concerning the terminal operators, 22 responses were received and analyzed. The report of this analysis is displayed below.

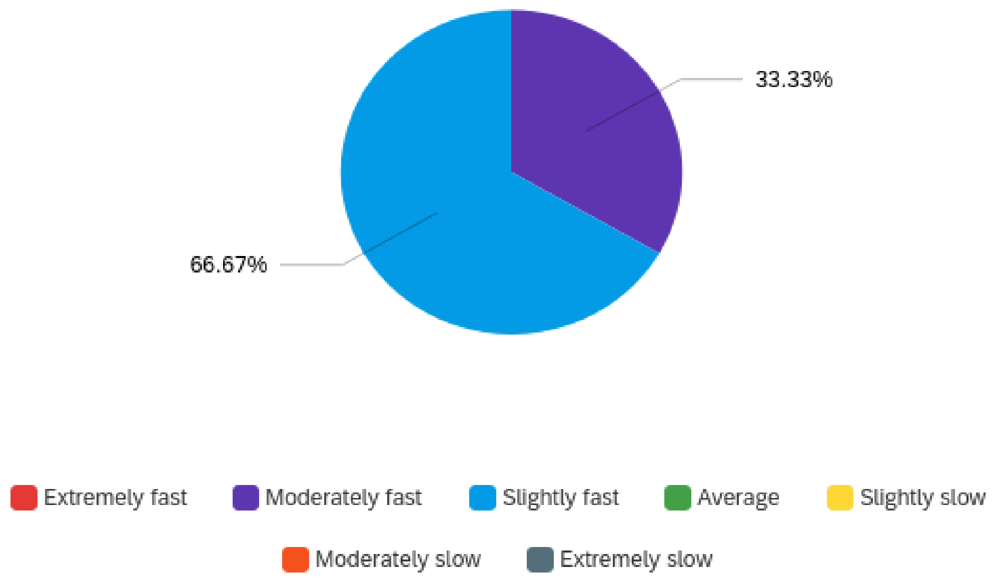
1. **Years of experience in the transport and logistics sector?**



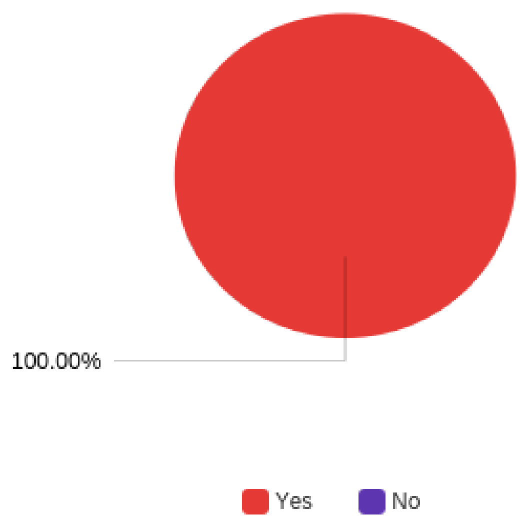
2. **Type of terminal operator?**



3. **How fast do container freight level and terminal operations recover from market disruptions such as COVID, recession, etc.?**



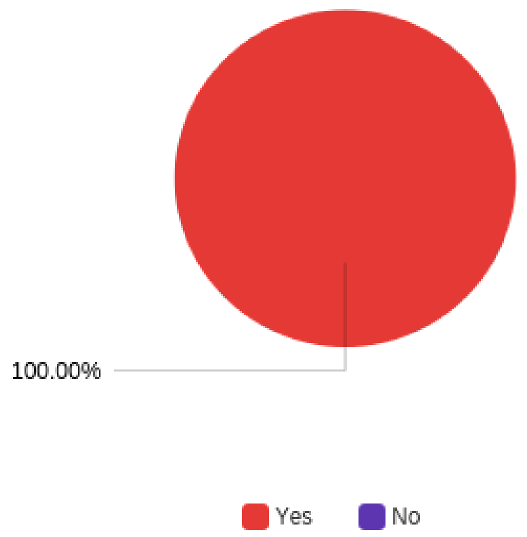
4. **Do you expect an increase in the current container volumes being handled at the terminals in the future?**



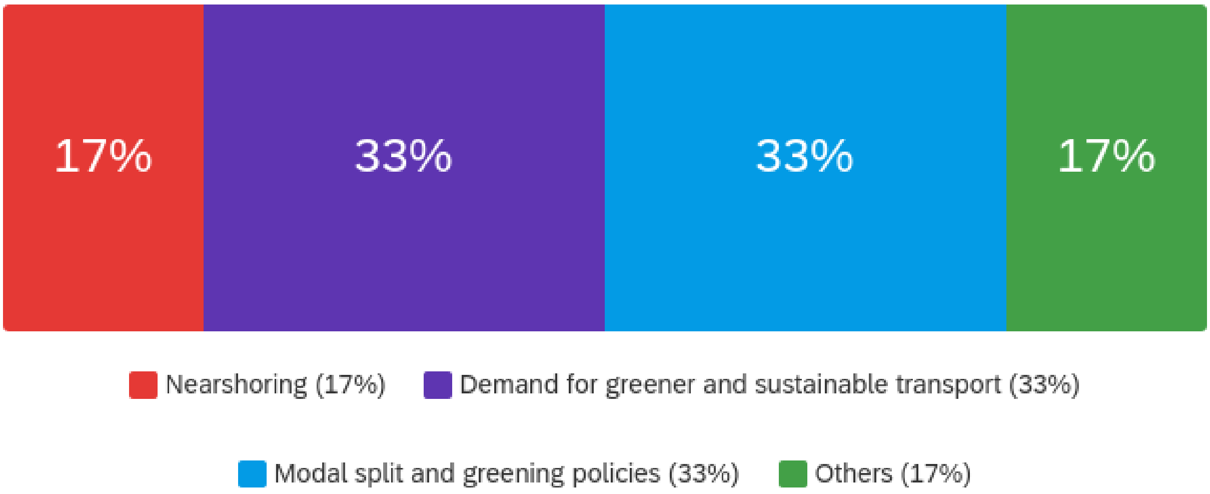
5. **What are the factors that might contribute to this growth? Please specify below?**

- More companies going for the "green way".
- Road congestion.
- More recognition of the potential of inland barges.
- Raising the bridge level (e.g Albert Canal) to allow for the loading of more containers per vessel.
- Clients with bigger volumes preferring inland terminals and vessels to reduce detention charges in ports.
- Evolving global trade (Asia-Europe) and the ongoing scale increase in this trade route.
- Consolidation and integration among global hubs, shipping alliances and hinterland networks.
- A lot of companies trying to reduce their CO^2 emissions.

6. **Do you expect to see an increase in the modal share of container IWT in the future?**



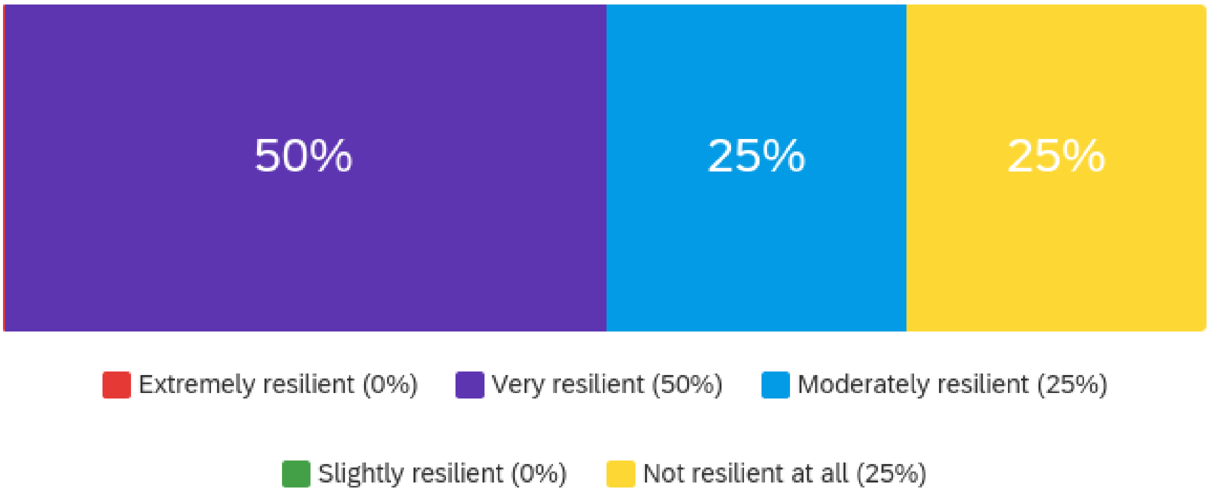
7. **What are the factors that might contribute to this increase?**



For response(s) with others, the main factors are:

- The logistics patterns and digital transformation.
- The important IT innovations for container ports.

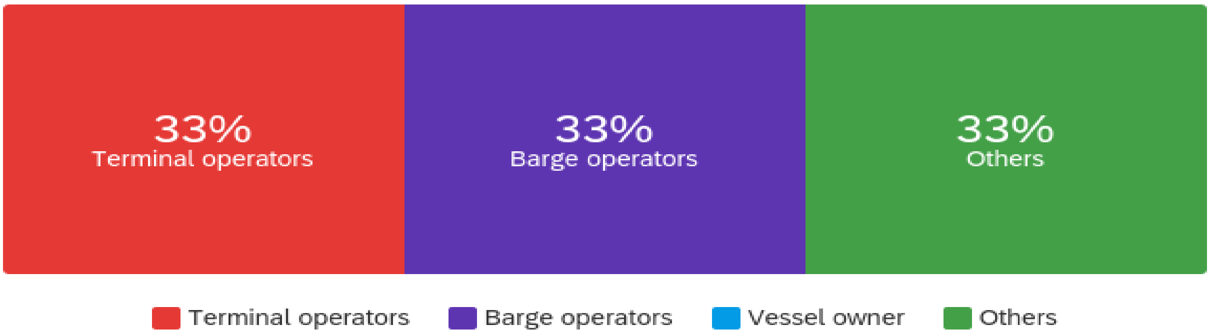
8. **In your opinion, how resilient are container terminal operations?**



9. **What are the factors that would make container terminal operations more resilient?**

- A better, quicker, more trustworthy handling in the port.
- More capacity for smaller barges in the port
- Reduction of the impact of sea-going vessel's operations and other disruptions (e.g Fogg, holidays.)
- Night opening of more deep-sea terminals.
- Flexibility in container barging schedules. (Flexibility in terms of last-minute changes in the number of containers per quay).

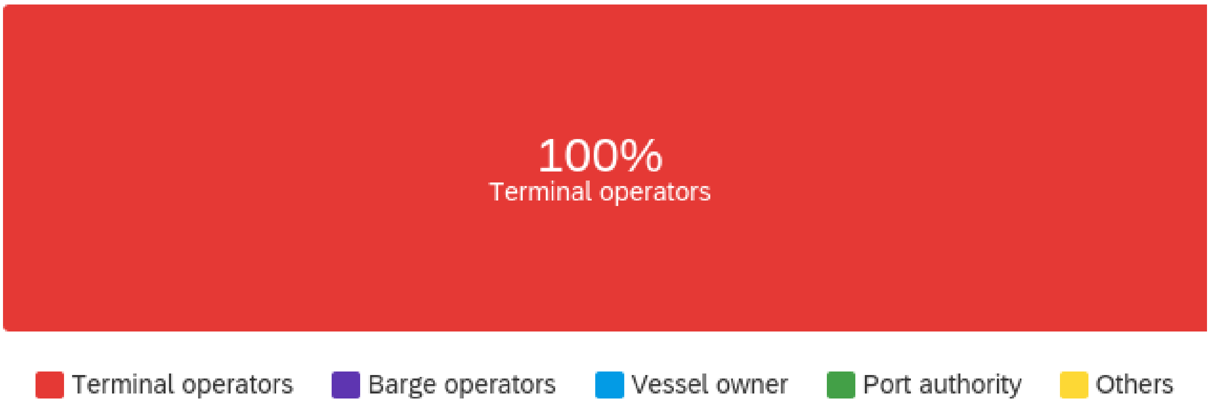
10. **Who in your opinion/at your company determines the sailing schedules of container inland vessels?**



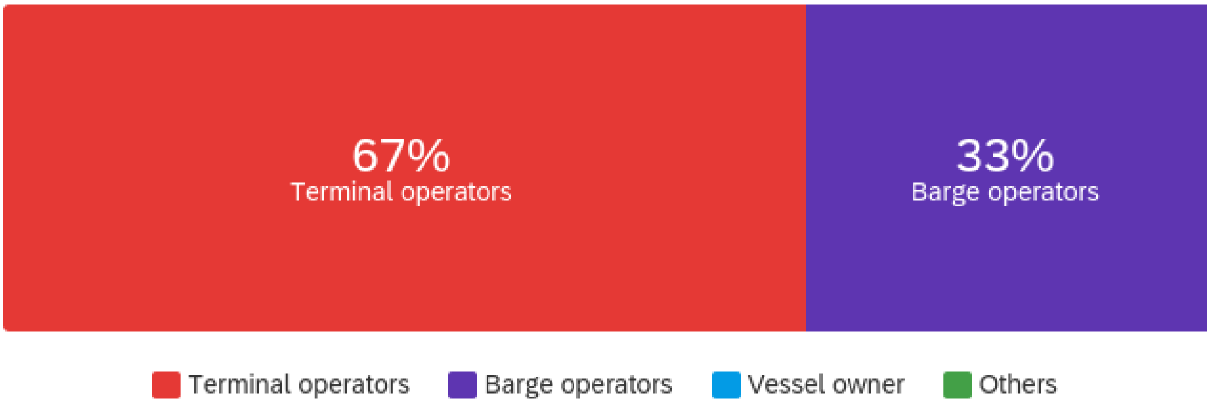
Response(s) of others include;

Barge operators, but is highly dependent on quay handling at the port.

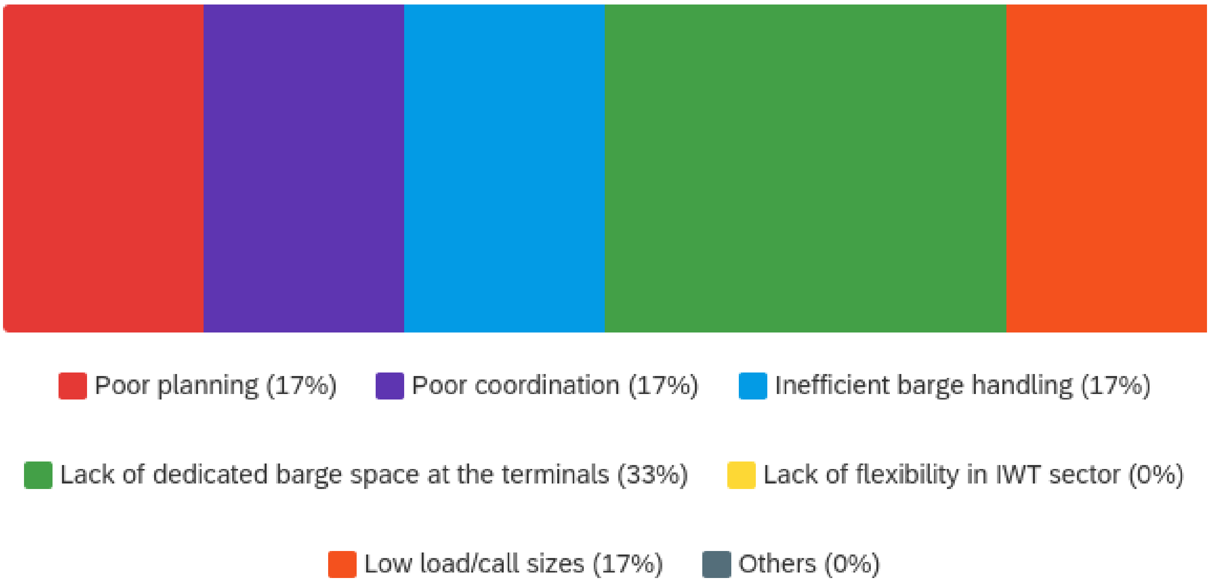
11. **Who in your opinion/at your company plans and sets the ETD and ETA of container inland vessels for terminal visits?**



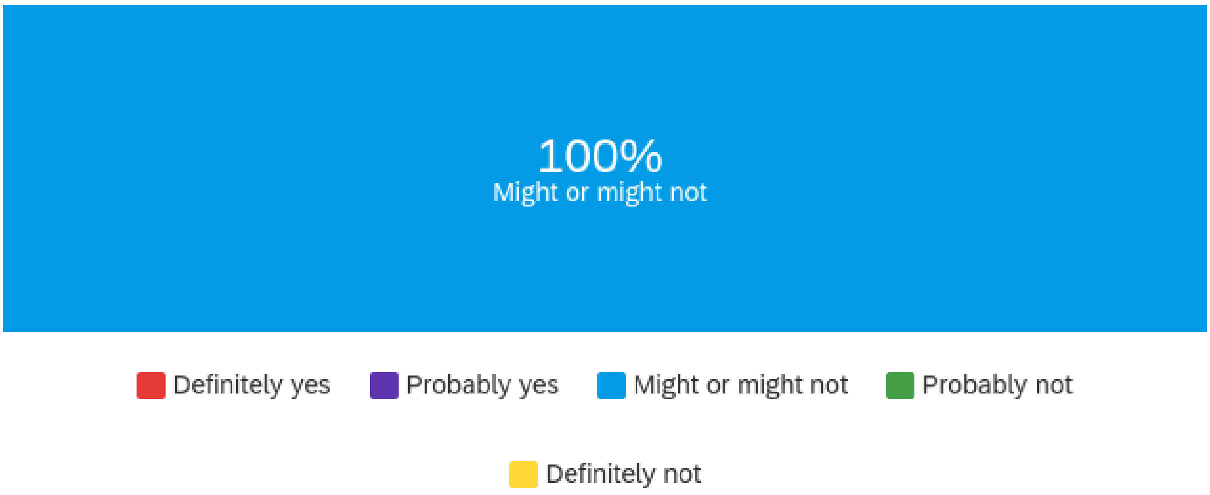
12. **Who decides on the planning and organization of container barge operations?**



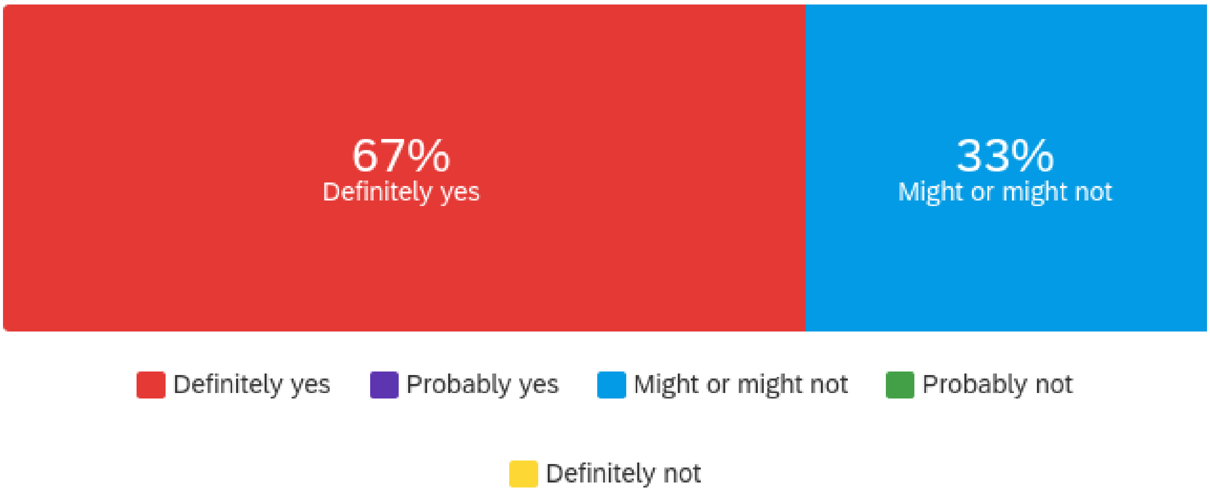
13. In your opinion, what do you find to be the current challenges facing container barge handling in terminals?



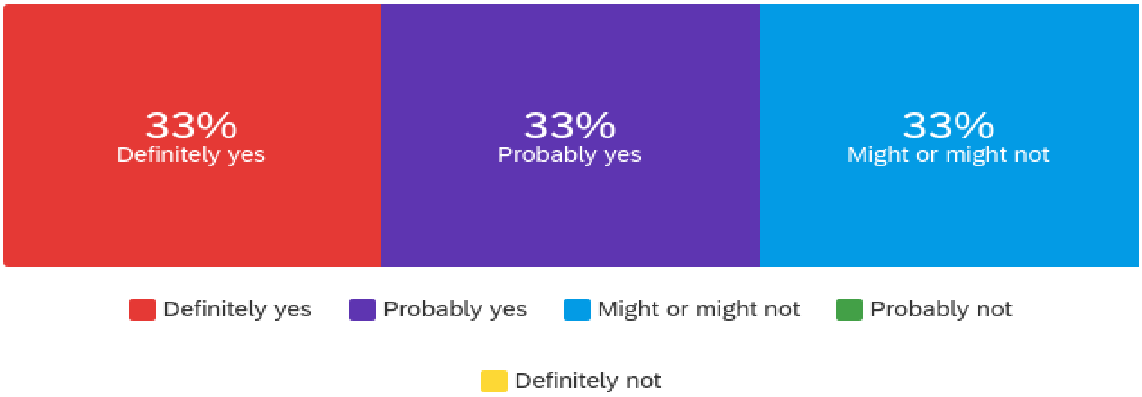
14. Would you consider prioritizing the handling of container barges if they have higher load sizes?



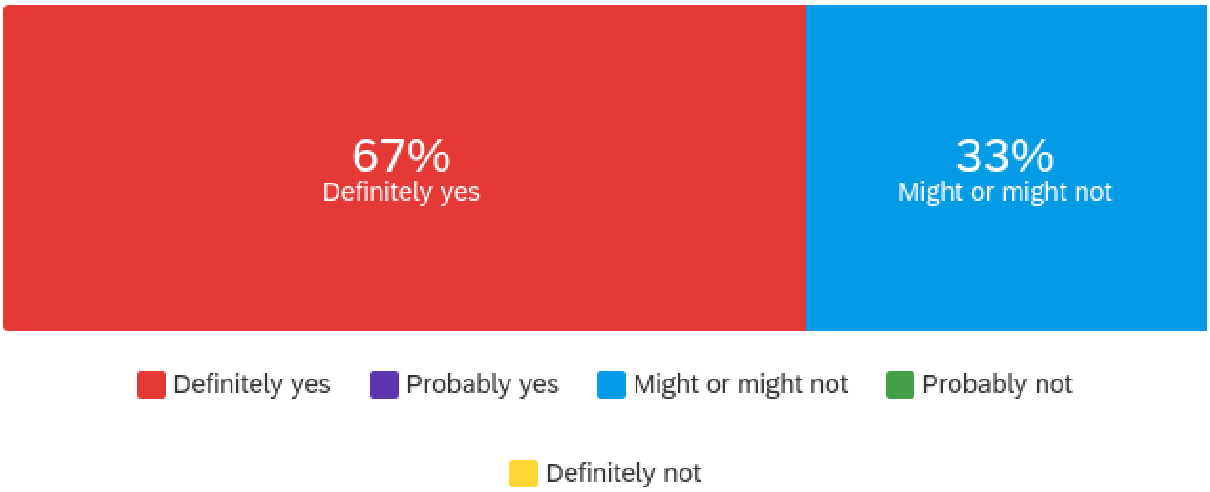
15. **Would you consider prioritizing the handling of container barges if their schedules are better planned?**



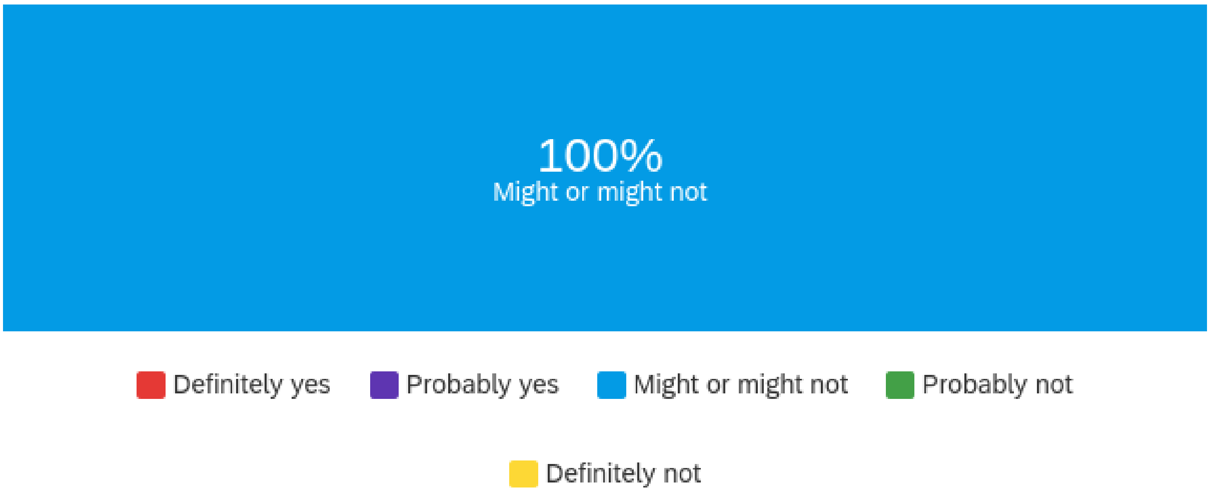
16. **Would you consider prioritizing the handling of container barges if they are better coordinated?**



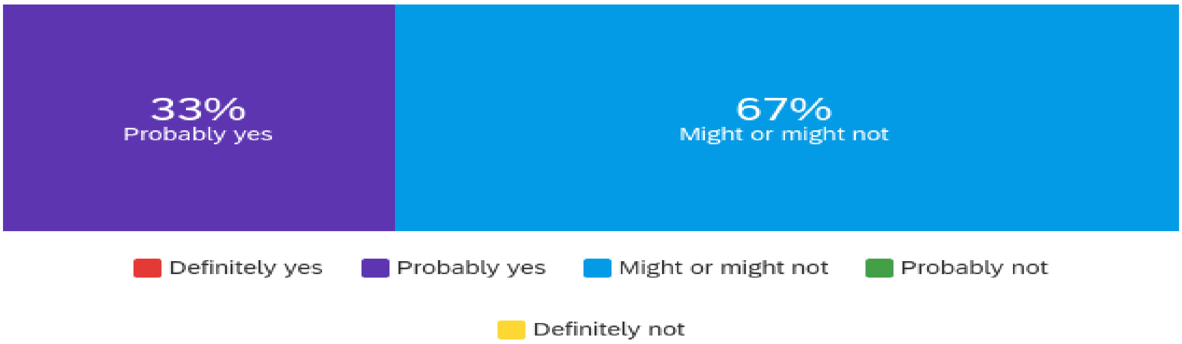
17. **Would you consider prioritizing the handling of container barges if they have dedicated and handling terminal space?**



18. Would you consider prioritizing the handling of container barges if they are more flexible?



19. Would you consider prioritizing the handling of container barges if they are more efficient?



20. What other factors would make you consider prioritizing the handling of container barges?

- Stable planning and handling of deep-sea vessels.
- Cost

Appendix D

Cargo flow, Distance, sail time, services and occupation rate of hinterland regions for Ports of Rotterdam and Antwerp

ROTTERDAM						
Region	**Import volume [TEUs]**	**Export volume [TEUs]**	**Distance [km]**	**Time [hr]**	**Services**	**Occupation**
BE22	48662	4104	233	19	189	55%
BE23	288188	32802	175	14	800	78%
BE25	87598	5519	223	15	270	67%
CH03	177029	16798	860	18	400	95%
DE11	0	4648	736	23	16	57%
DE12	13192	3021	673	69	163	19%
DE13	2088	2136	858	54	75	11%
DE71	22307	28348	529	69	160	62%
DEA1	402797	183850	258	43	1563	73%
DEA2	37054	22469	331	21	240	48%
DEB1	9795	9367	434	27	58	65%
DEB3	172465	48850	586	35	562	77%
FRF1	17910	20464	923	47	146	51%
NL22	54805	26145	145	74	654	24%
NL31	35208	57630	101	12	312	58%
NL32	84436	131231	144	8	993	42%
NL34	33494	40181	172	12	400	36%
NL41	115328	144269	110	14	3189	16%
NL42	43977	38364	259	9	1000	16%
ANTWERP						
Region	**Import volume [TEUs]**	**Export volume [TEUs]**	**Distance [km]**	**Time [hr]**	**Services**	**Occupation**
BE22	6850	18638	91	7	275	18%
BE23	12385	24353	87	7	400	18%
BE24	3401	14448	42	3	300	12%
BE25	163011	102007	128	10	600	86%
BE33	12685	46247	138	11	250	46%
CH03	27875	25808	885	71	180	58%
DE11	4345	7390	761	61	175	13%
DE12	15654	34258	698	56	141	69%
DE13	1491	7483	883	71	101	17%
DE71	6038	7743	554	45	203	13%
DEA1	56223	163721	283	23	870	49%
DEA2	12103	30901	356	29	241	35%
DEB1	9689	44069	459	37	184	57%
DEB2	657	9639	559	45	150	13%
DEB3	69422	97953	611	49	618	53%
FRF1	22994	79406	948	76	252	79%
NL22	9579	12398	170	14	400	11%
NL31	27573	232	182	15	98	55%
NL32	278516	205043	225	18	993	95%
NL41	83951	121367	122	5	444	90%
NL42	32576	77476	164	10	450	48%

Appendix E

Detailed analysis of individual regions linked to the MMTs in ports of Antwerp and Rotterdam

1: Case summary analysis for Antwerp

	BE21 - Barge Benefit						BE21 - Shipper Benefit					
	Min			Max			Min			Max		
Regions	**MMTs**	**MMTs 2018**	**% Δ**	**MMTs**	**MMTs 2018**	**% Δ**	**MMTs**	**MMTs 2018**	**% Δ**	**MMTs**	**MMTs 2018**	**% Δ**
BE22	-1,67	-5,8	-247%	2,66	16,16	507%	-5,95	-10,23	-72%	-1,61	11,83	836%
BE23	-1,46	-5,62	-285%	2,91	16,54	468%	-5,73	-10,05	-75%	-1,36	12,21	1001%
BE24	11,27	5,38	-52%	18,02	39,59	120%	6,99	0,95	-86%	13,75	35,26	156%
BE33	-15,75	-17,43	-11%	-14,04	-9,33	34%	-20,02	-21,75	-9%	-18,31	-13,66	25%
CH03	-17,04	-17,83	-5%	-16,31	-12,79	22%	-21,28	-22,08	-4%	-20,58	-17,12	17%
DE11	7,2	1,86	-74%	13,18	32,21	144%	2,92	-2,57	-188%	8,91	27,88	213%
DE12	-	-14,85	-	-	-14,85	-	-	-19,18	-	-	-19,18	-
DE13	-0,67	-4,94	-638%	3,85	17,97	367%	-4,95	-9,36	-89%	-0,42	13,64	3348%
DE71	6,8	1,52	-78%	12,72	31,5	148%	2,53	-2,91	-215%	8,45	27,17	222%
DEA1	-14,99	-15,84	-6%	-14,93	-10,45	30%	-19,38	-20,22	-4%	-19,32	-14,78	24%
DEA2	-12,82	-15,43	-20%	-10,57	-4,03	62%	-17,09	-19,86	-16%	-14,84	-8,36	44%
DEB1	-16,13	-12,52	22%	-16,13	-12,52	22%	-20,4	-16,85	17%	-20,4	-16,85	17%
DEB2	6,46	1,22	-81%	12,3	30,87	151%	2,18	-3,21	-247%	8,04	26,54	230%
DEB3	-16,93	-17,41	-3%	-15,45	-11,47	26%	-21,2	-21,67	-2%	-19,71	-15,8	20%
NL22	14,26	7,97	-44%	21,57	45,01	109%	9,99	3,54	-65%	17,3	40,68	135%
NL31	-17,29	-18,85	-9%	-15,87	-12,12	24%	-21,57	-23,17	-7%	-20,14	-16,46	18%
NL42	-16,08	-17,73	-10%	-14,43	-9,93	31%	-20,35	-22,05	-8%	-18,7	-14,26	24%

2: Case summary analysis for Rotterdam

Regions	NL33 - Barge Benefit						NL33 - Shipper Benefit					
	Min			Max			Min			Max		
	MMTs	MMTs 2018	% Δ	MMTs	MMTs 2018	% Δ	MMTs	MMTs 2018	% Δ	MMTs	MMTs 2018	% Δ
BE22	-12,17	-12,43	-2%	-10,87	-7,04	35%	-16,71	-16,95	-1%	-15,4	-11,67	24%
BE25	-	-9,7	-	-	-9,7	-	-	-14,32	-	-	-14,32	-
DE11	-	-9,85	-	-	-7,59	-	-	-14,39	-	-	-12,21	-
DE12	1,75	-2,31	-232%	5,78	18,15	214%	-2,79	-6,87	-146%	1,21	13,53	1015%
DE13	18,3	12	-34%	25,43	48,14	89%	13,76	7,44	-46%	20,86	43,51	109%
DE71	-	-10,77	-	-	-8,69	-	-	-15,31	-	-	-13,31	-
DEA2	-10,93	-10,79	1%	-9,58	-5,29	45%	-15,47	-15,35	1%	-14,15	-9,91	30%
DEB1	-	-12,01	-	-	-9,2	-	-	-16,53	-	-	-13,83	-
FRF1	-10,37	-11,37	-10%	-10,16	-6,17	39%	-14,89	-15,92	-7%	-14,73	-10,8	27%
NL22	-2,5	-5,98	-139%	0,74	10,47	1308%	-7,04	-10,54	-50%	-3,82	5,84	253%
NL31	-	-11,02	-	-	-7,9	-	-	-15,54	-	-	-12,53	-
NL32	-9,97	-11,42	-15%	-8,12	-3,06	62%	-14,51	-16,01	-10%	-12,69	-7,69	39%
NL34	-7,57	-10,9	-44%	-6,02	0,15	102%	-12,16	-15,46	-27%	-10,58	-4,47	58%
NL41	6,54	1,83	-72%	11,47	26,84	134%	2	-2,72	-236%	6,91	22,21	222%
NL42	6,24	1,57	-75%	11,12	26,29	137%	1,7	-2,98	-275%	6,55	21,67	231%

3: MMTs summary sensitivity analysis for Antwerp- Barge operators

BE21 – Barge Benefit									
Regions	**MMTs**	**2 MMTs**	**% Δ**	**4 MMTs**	**% Δ**	**6 MMTs**	**% Δ**	**8 MMTs**	**% Δ**
BE22	2,66	5,3	99%	2,57	-4%	2,08	-22%	2,5	-6%
BE23	2,91	5,55	91%	2,82	-3%	2,33	-20%	2,76	-5%
BE24	18,02	20,66	15%	17,92	-1%	17,43	-3%	17,86	-1%
BE33	-14,04	-	-	-14,67	-4%	-15,16	-8%	-14,2	-1%
CH03	-16,31	-	-	-16,83	-3%	-17,32	-6%	-16,89	-4%
DE11	13,18	15,82	20%	13,09	-1%	12,6	-4%	13,02	-1%
DE13	3,85	6,49	69%	3,75	-2%	3,27	-15%	3,69	-4%
DE71	12,72	15,36	21%	12,62	-1%	12,13	-5%	12,56	-1%
DEA1	-14,93	-	-	-	-	-	-	-14,93	0%
DEA2	-10,57	-	-	-10,66	-1%	-11,15	-6%	-10,72	-1%
DEB1	-16,13	-	-	-	-	-	-	-	-
DEB2	12,3	14,94	21%	12,21	-1%	11,72	-5%	12,15	-1%
DEB3	-15,45	-	-	-	-	-16,03	-4%	-16,07	-4%
NL22	21,57	24,21	12%	21,48	0%	20,99	-3%	21,41	-1%
NL31	-15,87	-13,23	17%	-15,97	-1%	-16,46	-4%	-16,03	-1%
NL42	-14,43	-	-	-14,53	-1%	-15,02	-4%	-14,59	-1%

4: MMTs summary sensitivity analysis for Antwerp- Shippers

BE21 – Shipper Benefit									
Regions	**MMTs**	**2 MMTs**	**% Δ**	**4 MMTs**	**% Δ**	**6 MMTs**	**% Δ**	**8 MMTs**	**% Δ**
BE22	-1,61	1,08	167%	-1,74	-8%	-2,15	-34%	-1,88	-17%
BE23	-1,36	1,33	198%	-1,49	-10%	-1,9	-40%	-1,63	-20%
BE24	13,75	16,44	20%	13,62	-1%	13,2	-4%	13,47	-2%
BE33	-18,31	-	-	-18,9	-3%	-19,45	-6%	-18,59	-2%
CH03	-20,58	-	-	-21,06	-2%	-21,61	-5%	-21,14	-3%
DE11	8,91	11,6	30%	8,78	-1%	8,37	-6%	8,64	-3%
DE13	-0,42	2,27	640%	-0,55	-31%	-0,97	-130%	-0,7	-66%
DE71	8,45	11,14	32%	8,32	-2%	7,9	-6%	8,17	-3%
DEA1	-19,32	-	-	-	-	-	-	-19,32	0%
DEA2	-14,84	-	-	-14,97	-1%	-15,38	-4%	-15,11	-2%
DEB1	-20,4	-	-	-	-	-	-	-	-
DEB2	8,04	10,73	33%	7,91	-2%	7,49	-7%	7,76	-3%
DEB3	-19,71	-	-	-	-	-20,26	-3%	-20,31	-3%
NL22	17,3	19,99	16%	17,17	-1%	16,76	-3%	17,02	-2%
NL31	-20,14	-17,45	13%	-20,27	-1%	-20,69	-3%	-20,42	-1%
NL42	-18,7	-	-	-18,83	-1%	-19,25	-3%	-18,98	-1%

5: MMTs summary sensitivity analysis for Rotterdam- Barge operators

NL33 – Barge Benefit									
Regions	**MMTs**	**2 MMTs**	**% Δ**	**4 MMTs**	**% Δ**	**6 MMTs**	**% Δ**	**8 MMTs**	**% Δ**
BE22	-10,87	-	-	-	-	-	-	-10,87	0%
DE12	5,78	1,01	-82%	4,99	-14%	5,52	-5%	5,78	0%
DE13	25,43	23,36	-8%	25,04	-2%	25,17	-1%	25,43	0%
DEA2	-9,58	-	-	-10,14	-6%	-9,84	-3%	-9,58	0%
FRF1	-10,16	-	-	-10,77	-6%	-10,42	-3%	-10,16	0%
NL22	0,74	-1,33	-279%	0,35	-53%	0,48	-35%	0,74	0%
NL32	-8,12	-	-	-	-	-	-	-8,12	0%
NL34	-6,02	-9,55	-59%	-	-	-6,28	-4%	-6,02	0%
NL41	11,47	-	-	11,08	-3%	11,21	-2%	11,47	0%
NL42	11,12	9,04	-19%	10,72	-4%	10,85	-2%	11,12	0%

6: MMTs summary sensitivity analysis for Rotterdam- Shippers

NL33 – Shipper Benefit									
Regions	**MMTs**	**2 MMTs**	**% Δ**	**4 MMTs**	**% Δ**	**6 MMTs**	**% Δ**	**8 MMTs**	**% Δ**
BE22	-15,4	-	-	-	-	-	-	-15,4	0%
DE12	1,21	-3,64	-400%	0,47	-61%	0,93	-23%	1,21	0%
DE13	20,86	18,53	-11%	20,51	-2%	20,58	-1%	20,86	0%
DEA2	-14,15	-	-	-14,65	-4%	-14,43	-2%	-14,15	0%
FRF1	-14,73	-	-	-15,36	-4%	-15,01	-2%	-14,73	0%
NL22	-3,82	-6,15	-61%	-4,17	-9%	-4,11	-7%	-3,82	0%
NL32	-12,69	-	-	-	-	-	-	-12,69	0%
NL34	-10,58	-14,2	-34%	-	-	-10,87	-3%	-10,58	0%
NL41	6,91	-	-	6,56	-5%	6,62	-4%	6,91	0%
NL42	6,55	4,22	-36%	6,2	-5%	6,26	-4%	6,55	0%

7: MMTs 2018 summary sensitivity analysis for Antwerp- Barge operators

BE21 – Barge Benefit									
Regions	**MMTs 2018**	**2 MMTs**	**% Δ**	**4 MMTs**	**% Δ**	**6 MMTs**	**% Δ**	**8 MMTs**	**% Δ**
BE22	16,16	19,46	20%	15,23	-6%	15,61	-3%	15,34	-5%
BE23	16,54	19,85	20%	15,61	-6%	16	-3%	15,73	-5%
BE24	39,59	42,89	8%	38,66	-2%	39,04	-1%	38,77	-2%
BE33	-9,33	-	-	-13,05	-40%	-12,66	-36%	-10,15	-9%
CH03	-12,79	-9,49	26%	-13,73	-7%	-15,54	-21%	-13,61	-6%
DE11	32,21	35,52	10%	31,28	-3%	31,67	-2%	31,4	-3%
DE12	-14,85	-	-	-	-	-	-	-15,66	-5%
DE13	17,97	21,27	18%	9,64	-46%	17,43	-3%	17,15	-5%
DE71	31,5	34,81	10%	30,57	-3%	30,96	-2%	30,69	-3%
DEA1	-10,45	-	-	-	-	-10,99	-5%	-11,26	-8%
DEA2	-4,03	-0,72	82%	-4,96	-23%	-4,57	-14%	-4,84	-20%
DEB1	-12,52	-	-	-	-	-	-	-13,34	-7%
DEB2	30,87	34,18	11%	29,94	-3%	30,33	-2%	30,06	-3%
DEB3	-11,47	-	-	-12,4	-8%	-12,02	-5%	-12,29	-7%
NL22	45,01	48,32	7%	44,08	-2%	44,47	-1%	44,2	-2%
NL31	-12,12	-8,82	27%	-13,06	-8%	-12,67	-4%	-12,94	-7%
NL42	-9,93	-	-	-10,86	-9%	-10,47	-5%	-10,74	-8%

8: MMTs 2018 summary sensitivity analysis for Antwerp- Shippers

BE21 – Shipper Benefit									
Regions	**MMTs 2018**	**2 MMTs**	**% Δ**	**4 MMTs**	**% Δ**	**6 MMTs**	**% Δ**	**8 MMTs**	**% Δ**
BE22	11,83	15,27	29%	11,02	-7%	11,31	-4%	11,01	-7%
BE23	12,21	15,65	28%	11,41	-7%	11,69	-4%	11,4	-7%
BE24	35,26	38,7	10%	34,45	-2%	34,74	-1%	34,44	-2%
BE33	-13,66	-	-	-17,41	-27%	-16,91	-24%	-14,48	-6%
CH03	-17,12	-13,68	20%	-17,93	-5%	-19,79	-16%	-17,94	-5%
DE11	27,88	31,32	12%	27,08	-3%	27,36	-2%	27,06	-3%
DE12	-19,18	-	-	-	-	-	-	-19,99	-4%
DE13	13,64	17,08	25%	5,28	-61%	13,12	-4%	12,82	-6%
DE71	27,17	30,61	13%	26,37	-3%	26,65	-2%	26,35	-3%
DEA1	-14,78	-	-	-	-	-15,3	-4%	-15,59	-6%
DEA2	-8,36	-4,92	41%	-9,16	-10%	-8,88	-6%	-9,17	-10%
DEB1	-16,85	-	-	-	-	-	-	-17,67	-5%
DEB2	26,54	29,98	13%	25,74	-3%	26,02	-2%	25,73	-3%
DEB3	-15,8	-	-	-16,61	-5%	-16,32	-3%	-16,62	-5%
NL22	40,68	44,12	8%	39,88	-2%	40,16	-1%	39,87	-2%
NL31	-16,46	-13,01	21%	-17,26	-5%	-16,97	-3%	-17,27	-5%
NL42	-14,26	-	-	-15,06	-6%	-14,78	-4%	-15,07	-6%

9: MMTs 2018 summary sensitivity analysis for Rotterdam- Barge operators

NL33 – Barge Benefit									
Regions	**MMTs 2018**	**2 MMTs**	**% Δ**	**4 MMTs**	**% Δ**	**6 MMTs**	**% Δ**	**8 MMTs**	**% Δ**
BE22	-7,04	-	-	-	-	-6,04	14%	-7,05	0%
BE25	-9,7	-	-	-	-	-	-	-9,71	0%
DE11	-7,59	-8,93	-18%	-6,68	12%	-6,59	13%	-7,59	0%
DE12	18,15	16,81	-7%	19,06	5%	19,15	6%	18,15	0%
DE13	48,14	46,8	-3%	49,04	2%	49,14	2%	48,13	0%
DE71	-8,69	-	-	-	-	-	-	-8,7	0%
DEA2	-5,29	-	-	-4,38	17%	-4,29	19%	-5,3	0%
DEB1	-9,2	-10,54	-15%	-8,3	10%	-	-	-9,21	0%
FRF1	-6,17	-	-	-5,27	15%	-5,18	16%	-6,18	0%
NL22	10,47	3,81	-64%	11,37	9%	11,46	10%	10,46	0%
NL31	-7,9	-	-	-	-	-6,9	13%	-7,91	0%
NL32	-3,06	-	-	-	-	-2,06	33%	-3,07	0%
NL34	0,15	-4,76	-3280%	1,05	605%	1,15	668%	0,14	-5%
NL41	26,84	25,5	-5%	27,74	3%	27,84	4%	26,83	0%
NL42	26,29	16,97	-35%	27,2	3%	27,29	4%	26,29	0%

10: MMTs 2018 summary sensitivity analysis for Rotterdam- Shippers

NL33 – Shipper Benefit									
Regions	**MMTs 2018**	**2 MMTs**	**% Δ**	**4 MMTs**	**% Δ**	**6 MMTs**	**% Δ**	**8 MMTs**	**% Δ**
BE22	-11,67	-	-	-	-	-10,56	9%	-11,67	0%
BE25	-14,32	-	-	-	-	-	-	-14,33	0%
DE11	-12,21	-13,56	-11%	-11,23	8%	-11,1	9%	-12,22	0%
DE12	13,53	12,18	-10%	14,5	7%	14,64	8%	13,52	0%
DE13	43,51	42,16	-3%	44,49	2%	44,62	3%	43,51	0%
DE71	-13,31	-	-	-	-	-	-	-13,32	0%
DEA2	-9,91	-	-	-8,94	10%	-8,81	11%	-9,92	0%
DEB1	-13,83	-15,18	-10%	-12,85	7%	-	-	-13,83	0%
FRF1	-10,8	-	-	-9,82	9%	-9,69	10%	-10,81	0%
NL22	5,84	-0,87	-115%	6,82	17%	6,95	19%	5,84	0%
NL31	-12,53	-	-	-	-	-11,42	9%	-12,53	0%
NL32	-7,69	-	-	-	-	-6,58	14%	-7,69	0%
NL34	-4,47	-9,44	-111%	-3,5	22%	-3,37	25%	-4,48	0%
NL41	22,21	20,86	-6%	23,19	4%	23,32	5%	22,21	0%
NL42	21,67	12,29	-43%	22,64	4%	22,78	5%	21,66	0%

Appendix F

NUTS 2 code and description

NUTS 2 Code	Description
BE10	Region de Bruxelles-Capitale / Brussels Hoofdstedelijk Gewest
BE21	Prov. Antwerpen
BE22	Prov. Limburg (B)
BE23	Prov. Oost-Vlaanderen
BE24	Prov. Vlaams-Brabant
BE25	Prov. West-Vlaanderen
BE31	Prov. Brabant Wallon
BE32	Prov. Hainaut
BE33	Prov. Liege
BE34	Prov. Luxembourg (B)
BE35	Prov. Namur
CH01	Region Lemanique
CH02	Espace Mittelland
CH03	Nordwestschweiz
DE11	Stuttgart
DE12	Karlsruhe
DE13	Freiburg
DE14	Tubingen
DE21	Oberbayern
DE22	Niederbayern
DE23	Oberpfalz
DE24	Oberfranken
DE25	Mittelfranken
DEA1	Dusseldorf
DEA2	Koln
DEA3	Munster
NL11	Groningen
NL12	Friesland (NL)
NL13	Drenthe
NL21	Overijssel
NL22	Gelderland
NL23	Flevoland
NL31	Utrecht
NL32	Noord-Holland
NL33	Zuid-Holland
NL34	Zeeland
NL41	Noord-Brabant
NL42	Limburg (NL)