Multi-Criteria Decision Analysis for Selecting Carriers for Overseas Tank Container Transport with Sustainability Objectives

Thesis MSc. Transport Infrastructure and Logistics (TIL)

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Preface

This master's thesis marks the end of my study period at the Delft University of Technology. The period during my Bachelor of which I first thought: when is studying finally over? And now think: may it please last a little longer? But every time comes to an end and I am proud of the result of the report that lies in front of you.

First and foremost, I must extend my deepest gratitude to my two university supervisors who have been very important to me during this journey. I would like to start by thanking Jafar Rezaei, my chair, whose extensive knowledge on Multi-Criteria Decision-Making (MCDM) methodologies, especially the Best Worst Method (BWM), has been invaluable. Your ability to provide concrete answers to many of my questions has been a true blessing. Thank you for your patience and expertise. Additionally, I would like to thank Arjan van Binsbergen, my second supervisor, for your insights into conceptual design and your comprehensive suggestions. Your constructive feedback has greatly enriched my work and helped me achieve my goals in shaping the final product of this thesis.

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Thank you all and enjoy the read!

P.J. Hennink
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Executive Summary

Global trade relies heavily on maritime transport, with tank container transport being crucial. Hoyer, a global logistics company, faces challenges in selecting the best carriers for transporting tank containers overseas. The objective of this research is to identify the best carriers for transporting tank containers overseas by using Multi-Criteria Decision-Making (MCDM) methods, specifically the Best-Worst Method (BWM) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). This research aims to bridge the gap in existing literature, which often lacks a comprehensive approach to sustainability in carrier selection. Sustainability encompasses three categories: economic, social and environmental, which are further used in this research. Earlier research focused on local contexts and did not specifically focus on overseas tanker container transport. The BWM, a relatively new method, is identified as a promising approach. Though not specifically used for overseas tank container transport before, BWM reliably prioritises criteria, improving carrier selection for global logistics.

The literature review highlights current research gaps and opportunities in carrier selection and sustainability. Interviews and secondary data analysis reveal insights into the existing carrier selection process. Furthermore, the interviews and literature review help to identify critical criteria for incorporating sustainability in carrier selection. The qualitative research ensures that the tool is developed to the company's specific needs and operational context. The MCDM tool uses BWM and TOPSIS. BWM determines the weights of the 15 selected criteria, requiring fewer comparisons due to its reliability and efficiency compared to other methods. The weights highlight the importance of criteria within the three categories. *Price*, *IMO Surcharge*, and *Transit-time* are critical economic criteria. Additionally, CO_2 *Emission per Shipment* and *ETS Fee* demonstrate to be important environmental criteria. The social-related criteria are generally equally important to each other. In parallel with BMW, carriers are sourced. Performance matrices are drawn up containing carriers and their scores on the criteria. TOPSIS is then applied to three important shipping lanes to evaluate carriers by calculating their Euclidean distance to ideal and non-ideal solutions, accommodating trade-offs between criteria like *Price* and *Service*.

The results reasonably match the company evaluations. However, integrating sustainability criteria impacts carrier evaluation mainly causing one place difference in ranking compared to the company. Economic criteria remain crucial, but social and environmental factors are also vital for balanced evaluations. The developed tool offers a more comprehensive evaluation than Hoyer's current lexicographic ordering approach, which prioritises *Price* above other criteria and evaluates carriers one criterion at a time, stopping once a significant difference is found. The tool balances various criteria, providing a robust, transparent, and practical method for carrier evaluation. Furthermore, sustainable carrier choices often involve additional costs, ranging from \$5 to \$300 per TEU (i.e. 25% to 0.56% of the original cost), depending on the shipping lane. Sensitivity analyses confirm the tool's robustness and adaptability to different weights and criteria changes. The analyses show it can handle variations in economic, social, and environmental weights, making it flexible for diverse contexts. Validation shows that a subjective criterion, *Operational Familiarity*, is also important for the company.

This research significantly enhances both practical logistics and academic literature. It improves Hoyer's carrier selection by integrating sustainability and advanced methodologies. The tool enables more informed, balanced, and sustainable carrier selection decisions. The structured implementation and continuous monitoring ensure ongoing value. Additionally, using it in negotiations could provide a competitive market advantage. By showing carriers their rankings compared to competitors, the company can motivate them to offer better pricing or terms. Furthermore, applying BWM and TOPSIS in selecting tank container carriers fills a gap in the literature. This study demonstrates that BWM instead of traditional methods like AHP can be used for decision-making in carrier selection incorporating sustainability. Future research should focus on expanding the tool's application to other regions, incorporating subjective criteria and more decision-makers, exploring additional MCDM methods and studying how to include changes due to external factors. The company could look into migrating the tool to Python for future use. Besides, improving the accuracy of data for criteria scores would contribute significantly.

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Abbreviations

Table 1: Abbreviations

Abbreviation	Definition
AHP	Analytical Hierarchy Process
BWM	Best-Worst Method
CR	Consistency Ratio
DM	Decision-Maker
EEOI	Energy Efficiency Operating Indicator
ETS	Emissions Trading System
(N)FC	(Non) Functional Constraint
(N)FO	(Non) Functional Objective
IBC	Intermediate Bulk Container
IMO	International Maritime Organisation
LTIFR	Lost Time Injury Frequency Rate
MCDM	Multi-Criteria Decision-Making
QBR	Quarterly Business Review
RFP	Request For Proposal
RFQ	Request For Quotation
TEU	Twenty-foot Equivalent Unit
TOPSIS	Technique for Order Preference by Similarity to Ideal Solutions
UN	United Nations

1 Introduction

In this chapter, the problem is introduced first. Hereafter, the scope is discussed, followed by the presentation of the research questions. Finally, the structure of the research is presented.

1.1. Problem introduction

Global trade relies heavily on maritime transport, with the international shipping industry handling over 80% of the world's trade in goods [50]. Tank container transport has grown significantly in maritime transport in recent years. The global tank container fleet expanded by 8.65% in 2022, exceeding the 7.3% growth observed in 2021 [102]. However, container transport in logistics is influenced by various factors. These factors include fluctuating demand subject to uncertainty, expansion of routes, development of new ports, blockage of routes and larger vessels requiring greater draught to be competitive [34]. With increasing competition in the global market, companies are under great pressure to find strategies to reduce costs to maintain their competitive position in their respective markets. In this context, selecting carriers that provide high-quality services, at competitive rates, and reliable transit-times is crucial for operational efficiency and competitiveness for logistics companies [30]. In logistics terms, a carrier refers to a company legally entitled to transport goods by land, water and air. They are responsible for the safe and timely delivery of goods from one place to another [92]. Selecting carriers is a critical procurement decision within logistics which has a large influence on business operations and competitiveness as it directly impacts the performance of an organisation [16]. Moreover, market liberalisation and globalisation lead to more choices, making it even more complex. Typically, multiple carriers operate on each route connecting two locations within the logistics network. Selecting carriers involves choosing a single carrier for transporting freight along a specific route [60, 59]. Therefore, selecting carriers is challenging due to ongoing uncertainty and complexity, particularly for specialised carriers in global supply chains [29]. Besides, transportation has a significant environmental impact, contributing greatly to Europe's greenhouse gas emissions [43, 108]. This leads to a growing demand to address sustainability in carrier selection [69, 107]. As Thomas et al. [98] suggest, adopting sustainable practices allows organisations to differentiate themselves competitively.

In addition, existing literature highlights challenges in carrier selection and a gap in ocean container carrier literature, particularly in tank container transport [72, 109, 60, 59, 37, 30, 29]. Besides, the existing literature on selecting ocean carriers mainly has a specific local focus and primarily addresses criteria for carrier selection. Furthermore, these criteria lack sustainability aspects, causing the need for future research [30]. While Multi-Criteria Decision-Making (MCDM) methods are common, a specific comparison of methods for carrier selection is missing [5, 72, 109, 30, 100]. Furthermore, the introduction of the Best-Worst Method (BWM) for multiple MCDM problems suggests its potential for carrier selection and incorporating sustainability [79, 68, 42, 63, 24, 54]. Lastly, sustainability encompasses economic, social, and environmental aspects. Including sustainability in carrier selection seems to be crucial due to environmental impact, acknowledging the need for more research, with existing literature emphasising challenges in integrating sustainability [108, 43, 21, 69, 107, 9, 30, 29]. Hence, the literature review highlights the complex nature of the carrier selection processes, presenting ongoing challenges and increasing recognition of sustainability factors. The knowledge gap that aims to be filled concerns further research on carrier selection for overseas tank container transport, specifically using BWM together with TOPSIS and the inclusion of sustainability objectives.

To fill the gap in the literature and gain a deeper understanding of carrier selection in the logistics industry, a case company is utilised. This approach provides valuable insights for future research and practical applications in similar contexts. The case company is Hoyer, a global logistics company that delivers comprehensive solutions for the safe handling and transportation of liquid products in the food, gas, mineral oil, and chemical industries. Hoyer achieves this by utilising tank containers, road tankers, and intermediate bulk containers (IBCs) across various modes of transportation, including road, rail, and sea [48]. Hoyer operates as a freight forwarder, not a producer or user, playing a crucial role in the logistics network. Figure 4.1 provides a schematic overview of Hoyer's role as a freight forwarder within the supply chain, acting as a link to ensure the efficient movement of goods. Their carrier requirements are driven by the need for profitability and sustainability goals, as well as the demands of their customers, who have specific requirements in these areas. Hoyer aims to enhance its carrier selection for overseas tank container transport to ensure safe and efficient logistics. This need has become more important due to current challenges in the Red Sea, prompting a shift from a 12-month to a 3-month tender period.

This study contributes significantly to a better understanding of carrier selection in logistics, revealing gaps and introducing innovative methodologies such as BWM. Addressing the lack of sustainability criteria in carrier selection promotes environmentally friendly practices in transport. In a broader social context, this research highlights the challenges in these processes and contributes to the growing demand for more sustainable and responsible logistics practices. The primary objective of this research is to identify the best carriers for transporting tank containers overseas by using MCDM, focusing on the application of BWM with TOPSIS and the integration of sustainability. The goal is to analyse and evaluate Hoyer's carrier selection process and develop a carrier selection tool using the existing carrier list as input. Furthermore, design implementation recommendations will be made to improve the carrier selection process. The research framework combines insights from literature review, interviews, and secondary data analysis to inform decision-making processes and contribute to the selection of carriers in logistics, specifically focusing on transporting tank containers overseas.

1.2. Scope

For this research, a defined scope establishes the boundaries and limits of the study. Establishing this scope clarifies the context in which the research findings apply and sets expectations about research coverage. This research focuses on the transport of tank containers. A tank container is a cylindrical container within a frame in which liquids are transported. Furthermore, this research is limited to the overseas transport of these tank containers, excluding freight transport or other forms of transport. In addition, only tank container transport under contract with the company is taken into account. Moreover, the findings are only applied to the three most important shipping lanes. Finally, the research is conducted from one region of the company, so the input data is based on that region.

1.3. Research questions

This research aims to identify the best carriers for transporting tank containers overseas with the use of Multi-Criteria Decision-Making (MCDM), emphasising the application of BWM in carrier selection and the inclusion of sustainability objectives. This will be accomplished by answering the following main research question:

"How is a carrier for transporting tank containers overseas selected considering the inclusion of sustainability objectives?"

This main research question will be answered by answering the following sub-questions:

1. How is the process of carrier selection currently executed?
2. What are essential requirements in the carrier selection process?
3. What sustainability criteria from both literature and internal experts should be considered for carrier selection?
4. How to find the relative importance (weights) of the criteria?
5. How to find the best carrier for transporting tank containers overseas?
6. How to implement it, in the case of the company?

1.4. Research structure

The remainder of the research is structured as follows. Firstly, the literature review is presented in chapter 2. Secondly, a description of the methodology is given in chapter 3. Thirdly, in chapter 4 the case study is elaborated. Fourthly, chapter 5 describes and discusses the results of this research. Finally, a conclusion and discussion are given in chapter 6.

2
Literature Review

In this chapter, various articles related to carrier selection and sustainability are reviewed. Finally, a conclusion and discussion on these articles are given. Literature for each section is sourced using specific keywords detailed in Table 2.1, utilising Google Scholar and Scopus as search engines. Additionally, backwards and forward snowballing helped to identify appropriate articles.

Table 2.1: Keywords used to find articles

Section	Used keywords
Carrier selection	”carrier selection” AND ”container” OR ”shipping”
Criteria carrier selection	”carrier selection” AND ”criteria” AND ”MCDM”
Sustainability	”carrier selection” AND ”sustainability”

2.1. Carrier selection

Extensive research exists on carrier selection and evaluation. Carrier selection is a specialised procurement decision with a significant history in logistics and physical distribution literature [29, 30, 37, 59, 60, 72, 109, 11]. The studies show that carrier selection plays a crucial role in influencing business operations and competitiveness. The carrier selection process stands out as a highly influential process with a direct impact on organisational performance. Selecting the right carrier is therefore becoming increasingly important [16]. Additionally, it is a challenging process due to ongoing uncertainty and complexity. Many global supply chains use specialised carriers to improve logistics competitiveness [29]. Selecting carriers that can deliver high-quality services at competitive freight rates and short transit times is a critical task for logistics management [30].

Studies that focus on selecting carriers for transporting tank containers overseas are limited and mainly have a specific local focus. For example, Brooks [12] focused on North Atlantic shipping in the United States, Canada, and Europe. Numerous studies have explored carrier selection across Asia, with research focused on Chinese shippers by Tiwari, Itoh, and Doi [99] and Wong, Yan, and Bamford [109], Taiwanese shippers by Shang and Lu [90], and Thai shippers by Banomyong and Supatn [7] and Setamanit and Pipatwattana [89]. Additionally, Peter Dzakah Fanam, Hong-Oanh Nguyen, and Stephen Cahoon [77] investigated carrier selection from the perspective of freight forwarders in Ghana, noting the importance of geographic differences in preferences. The differences between the regions are too large to directly compare the results. Moreover, the results cannot be directly applied to every region, because they are region-specific. Besides, research from Mohammaditabar and Teimoury [72] suggests that geographic location influences carrier selection.

Moreover, the existing literature on carrier selection mainly addresses carrier selection criteria [11, 109, 72, 89]. Those criteria are often identified and evaluated through diverse surveys and questionnaires [35, 89, 77, 52]. Additionally, it is noteworthy that the findings of the studies are regularly intended and useful for the carriers. Based on the results, carriers can adjust their strategies to attract multiple shippers [35, 89, 77, 109].

Furthermore, several studies try to enhance the understanding of carrier selection in logistics. Lin and Yeh [60] focuses on network reliability for carrier selection from Asia to Europe, uncovering various possibilities for optimising routes. Additionally, Gailus and Jahn [37] identifies 20 decision paths for container carrier selection, offering valuable insights into the tender process. Two recent studies on the selection of ocean container carriers [30, 29] provide valuable insights. Ergin, Feizollahi, and Kutlu [30] focuses on evolving criteria for carrier selection in the region between Turkey and the Eastern part of the United States. This study is noteworthy for being the first to apply the fuzzy Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS) method in ocean container carrier selection studies. It suggests that this method can be applied to different regions to identify additional characteristics influencing carrier selection. The study recommends using different Multi-Criteria Decision Making (MCDM) methods in future studies. The more recent study by Ergin and Alkan [29] employs a different MCDM method not previously used for container carrier selection, allowing criteria to interact. This study proposes that future research should encompass carrier selection for other segments, such as tankers or dry cargo, as existing literature predominantly focuses on container transportation.

In summary, a lot of research is found on carrier selection. Many existing studies on carrier selection, mainly focus on the criteria that should be used for selecting a carrier. Additionally, the studies do not widely discuss the process of deciding and the final impact of criteria on the decision process. Besides, there is a lack of focus on ocean carrier selection. The studies that are available on ocean carrier selection focus on a specific region. Lastly, there is a limited focus on containers specifically tank containers.

2.2. Criteria for carrier selection

As mentioned in section 2.1, much research on carrier selection delves into the criteria. Over the years, much literature has been collected on carrier selection criteria. The study of Ergin, Feizollahi, and Kutlu [30] resulted in 32 criteria used in carrier selection from 1984 till 2016. Table 2.2 gives an overview of these criteria. Furthermore, the article shows that from the freight forwarder's perspective, the top five criteria include equipment availability (C_{27}), low freight (costs) (C_1), on-time release of the bill of lading (C_{13}), confidentiality (C_{25}), and service schedule reliability (C_{16}). On the other hand, the five least important criteria for freight forwarders were inland cost (C_4), credit facility (C_2), quality certification (C_{24}), sales call regularity (C_9), and demurrage and detention tariff (C_3). These findings highlight the priority of competitive pricing and excellent service. Notably, environmental and social criteria are absent. As sustainability has grown in importance and this study only covers up to 2016, future research could benefit from exploring these criteria.

Table 2.2: Known criteria for carrier selection

Criterion	Source
1. Low freight	[18], [11], [12], [57]
2. Credit facility	[18], [57]
3. Demurrage and detention tariff	[109]
4. Inland cost	[18], [11]
5. Assigned customer representative	[76]
6. Customer communication management	[11] , [105]
7. On-time notification of the customer	[12] , [105]
8. Employee competence	[57], [65]
9. Sales call regularity	[11] , [65]
10. Cargo damaged and claim settlement process management	[11] , [57]
11. Cargo safety	[11] , [65]
12. Documentation quality and accurate invoicing	[53]
13. On-time release of bill of lading	[11] , [65]
14. Direct shipping to destination port	[18], [65]
15. Transit time	[65], [105]
16. Service schedule reliability	[65], [109]
17. Vessel capacity and easiness of booking	[18], [11]
18. Geographical coverage	[18], [57]
19. Serves frequency	[18], [11]
20. Container demurrage free time and detention free days	[66], [53]
21. Carrier reputation	[12] , [65]
22. Carrier financial stability	[53]
23. Professional appearance of sales personnel	[11] , [106]
24. Quality certification	[18], [65]
25. Confidentiality	[65], [105]
26. Safety of life at sea and marine pollution prevention policy	[65], [109]
27. Equipment availability	[18], [12]
28. Condition of container	[18], [12]
29. Special equipment availability	[18], [57]
30. Container tracking system	[18], [11]
31. Online reservation	[51], [53]
32. Electronic data interchange	[65], [106]

2.3. Sustainable carrier selection

Sustainability is a multidimensional concept encompassing economic, social, and environmental dimensions. From an economic standpoint, it relates to enduring financial viability, optimal resource utilisation, and the generation of value while maintaining fiscal stability. Social sustainability involves encouraging equitable and inclusive communities, prioritising social well-being, and enhancing the quality of life for both current and future generations. On the environmental dimension, sustainability requires careful management of natural resources, mitigation of environmental impact, biodiversity conservation, and proactive responses to climate change. This threefold framework acknowledges the complex relationship between economic wealth, social cohesion, and ecological resilience, forming the foundation for a sustainable and balanced future [97, 13].

Transportation has the most significant environmental impact among all logistics activities, contributing a substantial share of Europe's greenhouse gas emissions [108, 43]. In recent years, there has been a growing focus on the environmental sustainability of transportation, aligning with increased efforts to integrate sustainable practices into company supply chains [31]. Research is increasingly exploring how companies can incorporate environmentally friendly criteria into their carrier selection decisions, reflecting pressure to reduce environmental footprints and improve working conditions [21].

The selection of a transportation carrier is a standard procurement choice where sustainability has not always been a standard consideration, with price frequently being the dominant factor in procurement decisions [69, 107]. However, as highlighted in earlier research and reinforced in section 2.2, there has been a shift towards addressing the role of sustainability in carrier selection [69, 107]. The study by Thomas et al. [98] responds to this trend by proposing that adopting environmentally and socially sustainable business practices can help organisations stand out in a competitive market, indicating a move towards a more comprehensive approach in evaluating carriers.

Furthermore, the study of Bask et al. [9] has added and tested sustainability measures in carrier selection. Results of the study from Bask et al. [9] indicate that in the carrier selection process, sustainability functions as an order qualifier but not as an order winner. Carriers find it challenging to distinguish their offerings solely based on environmental criteria. Additionally, it is found that sustainability can be free if combined with operational efficiency and that environmentally proactive logistics service providers often financially outperform others [9].

The study by Davis-Sramek et al. [21] focuses on how the environmental and social performance of trucking carriers influences shippers' decision-making and trust. Conducting two experiments, one on long-term arrangements and another on short-term, the research assesses the role of sustainability in these choices. It specifically examines the impact of social and environmental factors, controlling for economic influences. The findings reveal that environmental factors are crucial in long-term selections, while social factors significantly affect short-term decisions. In alignment with this research, Ergin and Alkan [29] promotes the incorporation of more sustainability criteria in the selection process for ocean carriers in future studies. Furthermore, Rosano, Cagliano, and Mangano [85] identifies a literature gap, emphasising the need for an in-depth analysis of the interests and awareness levels of logistics operators regarding the adoption of sustainable practices.

To conclude, sustainability encompasses economic, social, and environmental aspects. Transportation, a major environmental contributor, is increasingly monitored, especially in Europe. Researchers aim to integrate sustainability into supply chains, particularly in carrier selection. Moreover, recent studies highlight the increasing importance of sustainability, suggesting the inclusion of more environmental factors in choosing ocean carriers in future research.

2.4. Conclusion literature review

The literature review provides a comprehensive overview of carrier selection in logistics, highlighting the recognised impact of carrier selection on organisational performance. Carrier selection is a specialised procurement decision important in logistics. The studies underscore the challenges associated with selecting carriers, highlighting the need for high-quality services, competitive freight rates, and dependable transit times. Notably, the review identifies a gap in the literature concerning the process of carrier selection and the broader regional focus. Additionally, there is a limited focus on ocean container carrier selection, specifically tank containers.

The top five criteria for carrier selection include equipment availability, low freight, timely release of waybills, confidentially and service schedule reliability. The absence of sustainability criteria underscores the need for future research in this area.

Sustainability encompasses economic, social, and environmental aspects. Sustainability in carrier selection emerges as a crucial theme, especially given the environmental impact of transportation activities. While studies acknowledge the need for more research into carrier selection and sustainability, existing literature emphasises the challenge that needs to be faced by including this in research.

2.5. Discussion literature review

The knowledge gaps found in the literature review and conclusion are especially interesting because they have important effects on logistics and transportation. The absence of a specific focus on overseas tank containers and sustainability in the carrier selection process raises questions about the extent to which the industry is responding to the growing importance of environmental issues. As sustainability becomes more important, the current lack of focus on environmental factors in choosing carriers makes it important to explore this in future research.

Furthermore, the growing importance of sustainability in all industries makes choosing carriers more complex. Considering sustainability in procurement, especially for transportation carriers, shows a need to align practices with environmental and social responsibility. This change highlights the importance of studying how to include sustainable criteria in the selection process for ocean carriers.

These gaps are interesting as they highlight crucial aspects requiring attention in ocean carrier selection research. The selection of the best carriers for logistics operations should not only consider traditional criteria but also integrate sustainability factors. Future research should aim to close these gaps to better enable the industry to make informed and sustainable responsible decisions on carrier selection.

3 Methodology

This chapter first presents an overview of the sub-research questions and the methodologies that help to answer them. Following this, the conceptual design is presented, based on the previously outlined methodologies. Thereafter, each method is explained in more detail. Finally, a short conclusion of this chapter is provided.

3.1. Overview methods

An overview of the methods used to answer the sub-research questions and contribute to answering the main research question is presented below. These methods collectively form the conceptual design, which is presented and discussed in the next section.

Table 3.1: Method(s) to answer sub-questions

Sub-question	Method(s)
1. How is the process of carrier selection currently executed?	Interviews & Secondary Data Analysis
2. What are essential requirements in the carrier selection process?	Interviews & Secondary Data Analysis & Literature review
3. What sustainability criteria from both literature and internal experts should be considered for carrier selection?	Literature Review & Interviews
4. How to find the relative importance (weights) of the criteria?	MCDM & BWM
5. How to find the best carrier for transporting tank containers overseas?	MCDM & TOPSIS
6. How to implement it, in the case of the company?	Qualitative Research

3.2. Conceptual design

The conceptual design gives an overview of the process and methods used in this research. It consists of a formal decision-making process and a so-called tool which are discussed first. Hereafter, the requirements are presented for both of them followed by a conclusion of the conceptual design.

3.2.1. Flow chart conceptual design

The flowchart presented in Figure 3.1 illustrates the key steps involved in this decision-making process. When the process of selecting carriers begins, the first step is to collect input through interviews, secondary data analysis, and literature review. This input will reveal the company's requirements. From these requirements, criteria will be identified, with the previously used method also contributing to this. These criteria can then be weighted using BWM. In parallel with this, carriers can be sourced, and they will provide information on criteria like costs and services. All the collected input, criteria, their weights, and carrier scores on criteria are then consolidated into a performance matrix. Following this matrix, the carriers can be evaluated and ranked using TOPSIS. The weights derived from BWM can be directly input into TOPSIS, which is why they are connected with a dotted line. An essential new addition to the process is a reflection moment. Previously, this step was not included, but interviews have shown it to be important. Even if a carrier scores high, certain circumstances might make this carrier less preferable. It is crucial to revisit the requirements and adjust them if necessary based on this reflection. Once the reflection is satisfactory, the final decision on the selection of a carrier can be made.

The flow chart distinguishes between the tool and the formal decision-making process. The formal decision-making process involves collecting inputs and making a decision, while the tool evaluates all inputs to facilitate this final decision. Moreover, identifying criteria, applying BWM, sourcing carriers, creating a performance matrix, and applying TOPSIS are all steps in MCDM methods or even an MCDM method by itself (BWM and TOPSIS). These steps can therefore be seen as the tool.

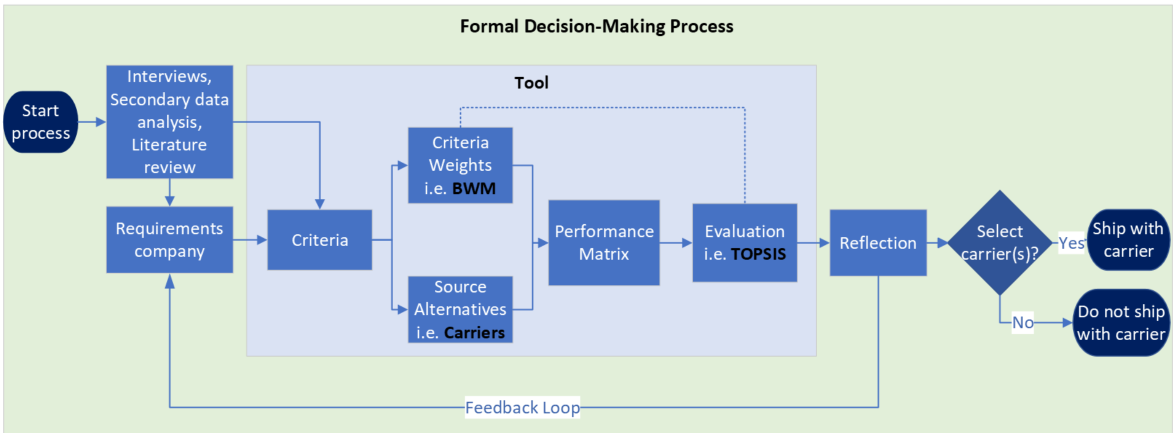


Figure 3.1: Flow chart conceptual design

3.2.2. Requirements

In this section, the requirements are discussed. The requirements are separately discussed for the tool and the decision-making process. The requirements are divided into constraints and objectives for both of them.

3.2.2.1. Constraints

Constraints represent properties of the system that the system must comply with and cannot be part of a trade-off. These constraints are further categorised into functional and non-functional properties. Functional constraints refer to what a system must do, it refers to a function. Non-functional constraints refer to attributes or characteristics that the system must have. An overview of the constraints for the tool is presented in Table 3.2 and for the decision-making process in which the tool is used in Table 3.3. Important to note is that if the tool does not comply with the constraints set up for this purpose then it is not a good tool and it can not be used. However, if an alternative (carrier) does not comply with the constraints set up for the decision-making process then this alternative is not further considered during this decision-making process.

3.2.2.1.1. Tool constraints

Table 3.2: Constraints - Tool

Functional constraints	Non-functional constraints
FC1. Must evaluate multiple carriers	**NFC1.** Must be compatible with other systems
FC2. Must evaluate based on the selected criteria	**NFC2.** Must be accessible to the company
FC3. Must identify differences within a criterion	**NFC3.** Must be understandable by the carriers
FC4. Must run on input delivered by the carriers	**NFC4.** Must have justifiable weights
FC5. Must run within 5 minutes	**NFC5.** Must be economically justifiable
FC6. Must reflect the company requirements	

The carriers must be evaluated by the tool as this is one of the main targets for the company. This allows them to choose the most preferred carriers (FC1). To make a distinction between different carriers multiple criteria need to be considered and based on these criteria the carriers must be evaluated (FC2). Within a criterion, different values may occur and these values must be valued differently (FC3). Furthermore, the carriers provide information on the different carriers and the tool must run on this input (FC4). Additionally, the running time of the tool must not take longer than five minutes (FC5). Besides, the tool must reflect the requirements of the company (FC6.).

Looking at the attributes and characteristics of the tool it firstly must be compatible with other systems of the company (NFC1). Secondly, the tool must be made accessible to the company, for example, the software in which the tool is made (NFC2). Thirdly, the tool must be understandable by the carriers so that they deliver the right input for the tool and how they are evaluated (NFC3). Fourthly, the weights that are used in the tool must be justifiable by the company (NFC4). This ensures that, even if changes occur, the tool can still be used effectively. Lastly, the tool must be economically justifiable to limit the chance of high investment costs (NFC5).

3.2.2.1.2. Decision-making process in which the tool is used constraints

Table 3.3: Constraints - Decision-making process

Functional constraints	Non-functional constraints
FC1. Must comply with relevant regulations	**NFC1.** Must be transparent to the carriers
FC2. Must consider sustainability objectives	**NFC2.** Must be accurate
FC3. Must use the tool for decision-making	**NFC3.** Must be understandable by the carriers
FC4. Must make a decision on selecting a carrier	**NFC4.** Must be repeatable
FC5. Must reflect and process reflection	

When looking at the decision-making process, it must comply with relevant regulations, such as contractual obligations (FC1). Furthermore, sustainability objectives must be considered when making decisions (FC2). The tool used to evaluate carriers must be employed in the decision-making process (FC3). Additionally, a decision must be made on whether to select a carrier (FC4). Moreover, the evaluation results from the tool should be reflected upon, and this reflection should also be incorporated into the process (FC5).

Besides, the decision-making process must be transparent to the carriers (NFC1). It must also be accurate and understandable by the carriers (NFC2&NFC3). Lastly, the decision-making process must be repeatable, so that if changes occur or a new tender process begins, it can be conducted again (NFC4).

3.2.2.2. Objectives

Objectives are requirements that express the design preferences and aspirations. While the design should strive to align with these objectives to the fullest extent possible, there is flexibility in the degree to which it can do so. Objectives are categorised into functional and non-functional objectives. A functional objective refers to what the design should do, indicating an action. A non-functional objective refers to what the design should be, indicating an attribute or characteristic. An overview of the objectives for the tool is presented in Table 3.4 and the decision-making process in Table 3.5.

3.2.2.2.1. Tool objectives

Table 3.4: Objectives - Tool

Functional objectives	Non-functional objectives
FO1. Should consider different views and opinions	**NFO1.** Should have an understandable output
FO2. Should take the least steps as possible	**NFO2.** Should be a cheap investment
FO3. Should run as fast as possible	**NFO3.** Should be well-organised
FO4. Should run on accurate data	**NFO4.** Should have an input without comments

It would be preferable that the tool considers different views and opinions (FO1). To ensure efficiency, it should take the fewest steps possible (FO2) and run as quickly as possible (FO3). Additionally, to make the outcomes as reliable as possible, the tool should operate on accurate data (FO4).

Preferred characteristics of the tool include having an understandable output (NFO1), being a low-cost investment for ease of direct use (NFO2), being well-organised (NFO3), and having an input without comments, making it easier to understand (NFO4).

3.2.2.2.2. Decision-making process in which the tool is used objectives

Table 3.5: Objectives - Decision-making process

Functional objectives	Non-functional objectives
FO1. Should take as short time as possible	**NFO1.** Should be well-organised
FO2. Should satisfy all stakeholders	**NFO2.** Should be cost-effective
FO3. Should align with organisational goals	**NFO3.** Should have low resistance
FO4. Should mitigate risks	

For the decision-making process, it is preferred that it goes as quickly as possible (FO1). Additionally, it is important that all stakeholders involved in the decision-making process are satisfied (FO2). The process should also align with the overall goals of the company (FO3). Lastly, the process should mitigate risks (FO4), meaning it should account for potential issues, such as a carrier under-performing and not transporting the agreed-upon volumes.

The characteristics of the decision-making process include being well-organised (NFO1) and cost-effective (NFO2). Finally, it is preferred that the process encounters low resistance from all stakeholders (NFO3). This means the decision-making process should proceed smoothly with minimal effort and obstruction.

3.3. Interviews

To understand the current state of selecting carriers, requirements for carrier selection and what criteria should be considered for carrier selection interviews are conducted. The interviews are conducted with employees and key stakeholders involved in the carrier selection process at Hoyer. These individuals share insights into their daily work and potential criteria. The interviews are conducted on-site following the guideline from Hancock [44]. First, key participants are identified, by approaching employees. The interviews are conducted individually and at the office of Hoyer for increased comfort and better information quality. Besides, the face-to-face format helps to understand non-verbal cues during the conversation. The interview guide is semi-structured, primarily focusing on identifying criteria for carrier selection. Furthermore, each interview is recorded, and fully transcribed and notes are taken. This allows the researcher to remain active in the conversation. However, in case an interviewee rejects the recording, only handwritten notes are taken. Lastly, obtaining informed consent is vital. Respondents must understand the research intentions, potential publication of information, and the confidential and anonymous use of their data.

3.4. Secondary data analysis

Secondary data analysis helps in providing an answer to sub-questions one and two. This method provides insights into the current carrier selection process and requirements. For the analysis, the data must be gathered by Hoyer [86]. The first step is to get familiar with the data, how the data was collected, what categories the data contains, whether clusters need to be accounted for and so on. After collecting the data, various analytical approaches, such as process mapping, are employed to identify the current process.

3.5. Literature review

A literature review is used to find an answer to sub-questions two and three. As extensive research has already been undertaken on this subject, repeating studies without enough evidence is not effective. It is important to carefully evaluate and confirm ideas supported by several studies. According to Snyder [93], there are three main types of literature reviews: schematic, semi-systematic, and integrative. The literature review for this sub-question aligns with a systematic approach, aiming to uncover prior research in the field and make connections between findings. An advantage of this method is among other things that it can be used to determine if an effect is constant and by using this method bias can be minimised. Besides, all the advantages of this method, a downside is that the use of this method is not too common in business research, but it is increasing [93].

3.6. Multi-Criteria Decision-Making (MCDM)

Multiple methods have been used to study the carrier selection problem. The literature shows that carrier selection based on Multi-Criteria Decision-Making (MCDM) is regularly used for carrier selection [5, 109, 72, 100, 30]. MCDM is also chosen instead of, for example, Cost-Benefit Analysis (CBA), because the literature in section 2.2 shows that there are also criteria included in carrier selection that could not be expressed in monetary terms. The MCDM problem is based on multiple criteria, involving various qualitative and quantitative criteria and relies on a comprehensive comparison of carriers using a shared set of conventional criteria and measures. The divergent and conflicting selection decisions add complexity and risk to the task [100].

In the literature, no literature review can be found that discusses and compares multiple MCDM approaches specifically for carrier selection. There is only literature available in which a specific MCDM method is applied for selecting a carrier [5, 72, 77, 109, 30, 29, 100, 87]. However, from the articles, it can be concluded that the analytic hierarchy process (AHP) and fuzzy TOPSIS are used equally. When looking specifically at the literature on ocean carrier selection AHP is used slightly more often [77, 109, 29, 30, 87]. While various studies provide overviews of MCDM selection models, they often focus on specific periods [104, 22, 47, 14]. For instance, Dewayana, Pahlevi, and Septiani [23] cover methods from 2013 to 2020, introducing the Best-Worst Method (BWM), introduced in 2015 [79].

This research utilises a hybrid MCDM method involving the Best-Worst Method (BWM) for determining the weights of criteria and the Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS) for the final evaluation of the carriers. The use of this hybrid decision-making approach is widespread in supplier selection [64, 111, 40]. While examples in the literature mention the Analytical Hierarchy Process (AHP) for identifying criteria weights, BWM is preferred and is considered to outperform AHP [79].

3.7. Best-Worst Method (BWM)

As mentioned in section 3.6, the Best-Worst Method (BWM) is a relatively new method developed in 2015 [79]. This method is chosen for determining the criteria weights. The paper by Rezaei [79] introduces this new method, designed for addressing MCDM problems. This method determines weights through pairwise comparisons of the best and worst criteria or alternatives against others. Although the AHP is another commonly used method in the literature [47, 14], BWM is generally favoured over AHP. Current literature shows that BWM outperforms the existing MCDM method, AHP [79, 68, 42]. Compared to AHP, BWM is excellent in statistical validation [42, 73]. Furthermore, research shows that BWM is more effective and consistent compared to AHP and other MCDM methods [63]. A key advantage of BWM is its reduced need for extensive pairwise comparisons [103]. Additionally, BWM stands out for its minimal data requirements and time efficiency, distinguishing it from traditional MCDM methods [79]. The final weights from BWM are highly reliable and consistently derived, BWM can be used independently and it is a more simplifying process compared to AHP [79].

Although BWM is relatively new, it has already been widely used. It has been applied in various types of businesses. For example, it has already been used to select suppliers in: the edible oil industry [82], electronics manufacturing together with TOPSIS [64], in a plastic injection moulding company together with TOPSIS [111], in watch manufacturing together with alternative queuing method [62], in a plastic manufacturing company together with TOPSIS [94], in a Turkish furniture manufacturing company with fuzzy CODAS [101], in the oil and gas industry with Delphi and TOPSIS [40], and in a construction company to support the creation of a lean and sustainable construction supply chain [96].

In the literature, some articles on BWM concerning a carrier can be found [58, 25, 95, 84, 81]. However, those articles do not use BWM to select a carrier. This is noteworthy since carrier selection has been researched a lot and BWM has also been regularly used, particularly in the context of supplier selection. Another knowledgeable thing is that BWM over the past few years has been frequently used for sustainable supplier selection [24, 54].

Besides all the advantages there are also some disadvantages of BWM. The interpretation of criteria importance may vary among individuals, impacting the reliability of results. Furthermore, it has a limited sensitivity in capturing subtle differences in criteria importance and it can be complex in large decision models as determining the best and worst criteria might be difficult. The following steps are required to execute the BWM method:

Step 1 - Determine set of decision criteria

The first step involves finding and determining the important criteria $(c_1, c_2, ..., c_n)$ through interviews, secondary data analysis and literature review. The performance of the carriers will be evaluated based on these criteria. The values of the criteria must adhere to an interval or ratio scale for analysis. Besides, for the use of BWM, it is best to select not too many criteria, as this creates practical issues.

Step 2 - Determine best and worst criteria

In the second step, the best (e.g. most important, most desirable) and the worst (e.g. least important, least desirable) criteria are determined. The best and worst criteria are determined in general, meaning no comparison is made at this stage.

Step 3 - Determine preference of best criterion over other criteria

In the third step, the preference of the best criterion over all other criteria is determined using a number between 1 and 9. The meaning of those numbers is listed below.

1. **Equal** importance
2. Somewhat between Equal and Moderate

3. **Moderately** more important than
4. Somewhat between Moderate and Strong
5. **Strongly** more important than
6. Somewhat between Strong and Very Strong
7. **Very strongly** important than
8. Somewhat between Very strong and Absolute
9. **Absolutely** more important than

This results in the following Best-to-Others vector: A_B = (a_{B1}, a_{B2},...,a_{Bn}), where a_{Bj} gives an indication of the preference of the best criterion B over criterion j. In this case a_{BB} = 1. A rating of 1 thus indicates equal importance between criterion i and criterion j, and a rating of 9 signifies the highest importance of criterion i over criterion j.

Step 4 - Determine preference of worst criterion over other criteria

In the fourth step, the preference of the worst criterion over all other criteria is determined, again by using a number between 1 and 9 as shown above. This results in the following Others-to-Worst vector: A_W = (a_{1W}, a_{2W},...,a_{nW})^T, where a_{jW} gives an indication of the preference of criterion j over the worst criterion W. In this case a_{WW} = 1. A rating of 1 indicates equal importance between criterion i and criterion j, and a rating of 9 signifies the highest importance of criterion i over criterion j.

Step 5 - Find optimal weights

The fifth step is to determine the optimal weights $W = w_1, w_2, ..., w_n$. Initially, BWM uses a non-linear method, resulting in multiple optimal solutions. While multiple optimal weights can be beneficial in group decision-making, a unique solution is often preferred in other cases. The linear BWM model provides a unique solution, which is preferred in this research. Therefore the linear BWM, which is presented below, is used.

The goal is to determine the optimal weights for each criterion, such that the maximum absolute differences among the set of $\{|w_B - a_{Bj}w_j|$, $|w_W - a_{jW}w_j|\}$ for all j are minimised, which is translated to the following min-max model:

$$\min_j \max \left\{ \left| w_B - a_{Bj}w_j \right|, \left| w_j - a_{jW}w_W \right| \right\}$$

subject to:

$$\begin{aligned} \sum_j w_j &= 1 \\ w_j &\geq 0, \quad \text{for all } j \end{aligned} \tag{3.1}$$

This model is equal to the following linear programming model:

$$\min \xi^L$$

subject to:

$$\begin{aligned} \left| w_B - a_{Bj}w_j \right| &\leq \xi^L \quad \text{for all } j \\ \left| w_j - a_{jW}w_W \right| &\leq \xi^L \quad \text{for all } j \\ \sum_j w_j &= 1 \\ w_j &\geq 0, \quad \text{for all } j \end{aligned} \tag{3.2}$$

By solving the second model, the optimal weights $w_1, w_2, ..., w_n$ and optimal values of ξ^L are obtained.

Step 6 - Check reliability pairwise comparisons

A comparison is consistent when $a_{Bj} \times a_{jW} = a_{BW}$ for all j, where a_{Bj}, a_{jW}, and a_{BW} represent the preference of the best criterion over criterion j, criterion j over the worst criterion, and the best criterion over the worst criterion, respectively. However, inconsistencies can occur, which may arise from the decision maker's preferences, lack of concentration, or difficulty in assigning numerical values to qualitative criteria. To measure consistency in linear BWM, the indicator ξ^L is used which is obtained in the fifth step and reflects the overall consistency of the pairwise comparisons. A ξ^L value close to zero indicates higher consistency, with values below one considered sufficiently consistent. Furthermore. the value of ξ^L should be compared to the accepted threshold. If it is below this threshold, the comparisons are considered consistent. If this is not the case, the comparisons may need to be reviewed and adjusted [80].

3.8. Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS)

To answer sub-question five, TOPSIS is used. The TOPSIS method is well-established in MCDM analysis, often applied alongside BWM [64, 111, 40]. It is particularly suited for compensatory decision scenarios. TOPSIS evaluates alternatives by considering their Euclidean distance to both ideal and non-ideal solutions, accommodating compensatory effects for a nuanced assessment. This flexibility allows decision-makers to navigate trade-offs between criteria, crucial in complex decisions like carrier selection involving multiple dimensions such as cost, reliability, and sustainability.

In comparison to non-compensatory methods, TOPSIS provides the flexibility needed for nuanced decision problems, allowing consideration of trade-offs between different criteria. Unlike methods like AHP that may not explicitly address compensatory effects, TOPSIS excels in capturing the interaction between criteria in a compensatory manner. Its simplicity and flexibility make it advantageous, providing a practical and accessible solution for decision-makers.

Moreover, TOPSIS incorporates normalisation and aggregation, enhancing its scientific robustness. Normalisation ensures a fair comparison among criteria, reducing sensitivity to diverse scales, while aggregation synthesises criterion assessments for an overall performance measure. Considering the relative importance of criteria, TOPSIS allows for strategic weighting. In summary, the inclusion of normalisation and aggregation in TOPSIS promotes fair, balanced, and objective decision-making.

However, some downsides are that results can be sensitive to assigned weights, the assumptions of linearity might lead to oversimplifying and the ideal solution might be subjective. Regularly reviewing the decision-making process in response to changing needs promotes continuous improvement and adaptation. With TOPSIS, the various currently available carriers for transporting tank containers are evaluated, considering their proximity to the most optimal value. The TOPSIS method consists of seven steps, outlined as follows:

Step 1 - Create performance matrix

In the first step a performance matrix $(z_{ij})_{m \times n}$ is created. Before creating the performance matrix, the criteria, their weights and the carriers (alternatives) should be known. The matrix has carriers as rows and sustainability criteria as columns. Scores are assigned for each carrier-criterion combination and each criterion has an assigned weight determined by BWM. This provides a structured framework to assess carriers based on sustainability criteria [38]. An example layout of a performance matrix is shown in Table 3.6. This matrix structure supports a quantifiable and transparent assessment, as each criterion can be assigned quantitative measures. The z_{ij} scores in the performance matrix must be based on objective values that should be retrieved from the carriers based on their past and current operations and performances. By incorporating weighted criteria, decision-makers can express the relative importance of criteria. The visual representation of the matrix aids communication and understanding, while consistency checks ensure the reliability of assessments. The flexibility to adjust criteria suits the changing circumstances the company faces. In addition, the matrix facilitates the aggregation of scores for an overall performance measure. Aligned with MCDM methods, the performance matrix offers a scientifically based and structured approach, introducing objectivity, transparency and applicability into the decision-making process.

Table 3.6: Performance matrix

	w_1	w_2	$\dots$	w_n
	C_1	C_2	$\dots$	C_n
$Carrier_1$	z_{11}	z_{12}	$\dots$	z_{1n}
$Carrier_2$	z_{21}	z_{22}	$\dots$	z_{2n}
$\vdots$	$\vdots$	$\vdots$	$\dots$	$\vdots$
$Carrier_m$	z_{m1}	z_{m2}	$\dots$	z_{mn}

Step 2 - Normalise the performance matrix

In the second step, the matrix $R = (r_{ij})_{m\times n}$ is formed. This is done by normalising the matrix $(z_{ij})_{m\times n}$ with the following normalisation method:

$$r_{ij} = \frac{z_{ij}}{\sqrt{\sum_{k=1}^{m} x_{kj}^2}}, \quad i = 1, 2, \dots, m, \quad j = 1, 2, \dots, n. \tag{3.3}$$

Step 3 - Calculate the weighted normalised performance matrix

In this step, the weighted normalised performance matrix is calculated. This is done as follows:

$$t_{ij} = r_{ij} \cdot w_j, \quad i = 1, 2, \dots, m, \quad j = 1, 2, \dots, n, \tag{3.4}$$

where

$$w_j = \frac{W_j}{\sum_{k=1}^{n} W_k}, \quad j = 1, 2, \dots, n, \tag{3.5}$$

so that

$$\sum_{i=1}^{m} w_i = 1, \tag{3.6}$$

and W_j is the original weight given to the indicator v_j, $j = 1, 2, \dots, n$.

Step 4 - Determine the worst and the best carrier

The worst carrier ($Carrier_w$) and the best carrier ($Carrier_b$) are determined in the fourth step by:

$$\begin{aligned} Carrier_w &= \{\langle \max(t_{ij} \mid i = 1, 2, \dots, m) \mid j \in J_- \rangle, \langle \min(t_{ij} \mid i = 1, 2, \dots, m) \mid j \in J_+ \rangle\} \\ &\equiv \{t_{wj} \mid j = 1, 2, \dots, n\}, \\ Carrier_b &= \{\langle \min(t_{ij} \mid i = 1, 2, \dots, m) \mid j \in J_- \rangle, \langle \max(t_{ij} \mid i = 1, 2, \dots, m) \mid j \in J_+ \rangle\} \\ &\equiv \{t_{bj} \mid j = 1, 2, \dots, n\}, \end{aligned} \tag{3.7}$$

where,

$$\begin{aligned} J_+ &= \{j = 1, 2, \dots, n \mid j\} \quad \text{associated with the criteria having a positive impact, and} \\ J_- &= \{j = 1, 2, \dots, n \mid j\} \quad \text{associated with the criteria having a negative impact.} \end{aligned} \tag{3.8}$$

Step 5 - Calculate the Euclidean distances

In the fifth step the L^2-distance between the target carrier i and the worst condition $Carrier_w$ is calculated as follows:

$$d_{iw} = \sqrt{\sum_{j=1}^{n} (t_{ij} - t_{wj})^2}, \quad i = 1, 2, \dots, m, \tag{3.9}$$

and the distance between the alternative $\mathbf{t}_i$ and the best condition $\mathbf{t}_b$:

$$d_{ib} = \sqrt{\sum_{j=1}^{n} (t_{ij} - t_{bj})^2}, \quad i = 1, 2, \dots, m, \tag{3.10}$$

where d_{iw} and d_{ib} are L^2-norm distances from the target alternative i to the worst and best conditions, respectively.

Step 6 - Calculate the relative closeness to the ideal solution
The sixth step involves calculating the relative closeness to the ideal solution. This score is also called the performance score:

$$s_{iw} = \frac{d_{iw}}{d_{iw} + d_{ib}}, \quad 0 \leq s_{iw} \leq 1, \quad i = 1, 2, \ldots, m. \tag{3.11}$$

$s_{iw} = 1$ if and only if the carrier solution has the best condition, and $s_{iw} = 0$ if and only if the carrier solution has the worst condition.

Step 7 - Evaluate the carriers
In the last step, step 7, the carriers are evaluated according to s_{iw} $(i = 1, 2, \ldots, m)$.

3.9. Qualitative research

In the end, it is important that the results of the research can be applied in the case of the company. The tool should be developed to the company's specific needs. Moreover, qualitative research can help identify potential challenges in the carrier selection process, allowing the company to proactively address issues that may arise during integration and implementation. By involving key stakeholders, implementation runs more smoothly [36]. Furthermore, qualitative research will help in making suggestions for future use. In addition, to ensure that the implementation is correct and that it aligns with the company requirements, verification and validation are performed. Verification is done with the help of the conceptual model for which requirements have been drawn up that must ultimately be met. Validation is done based on expert feedback, provided by discussing results.

3.10. Conclusion methodology

In conclusion, this chapter outlined the methodologies used to address the sub-research questions and the main research question. The structured decision-making process is presented through a flowchart, detailing the functional and non-functional constraints and objectives. Key methods include interviews, secondary data analysis, literature review, and Multi-Criteria Decision-Making (MCDM) techniques specifically the Best-Worst Method (BWM) and TOPSIS. BWM determines the criteria weights, while TOPSIS evaluates carriers based on these weights. Qualitative research helps with implementing the tool within Hoyer's operations. This comprehensive approach ensures informed and sustainable carrier selection aligned with the company's goals and regulatory requirements.

4
Case Study

This chapter provides a detailed overview of the case company Hoyer, to which the methods are applied. The chapter starts with an introduction to the company and its problems. Following this, the stakeholders that are relevant to this research are explained. Subsequently, the various contract types, types of containers, and goods managed by the company are outlined. Additionally, the carriers and shipping lanes utilised over the years by the company are presented. Furthermore, the tender process and the current carrier selection are described. Finally, concluding remarks are provided.

4.1. Introduction to Hoyer and their problem

As outlined in chapter 3, the initial step involves conducting interviews and secondary data analysis and literature review to understand Hoyer, their current carrier selection process and the challenges they face. Hoyer is a global leading international logistics company specialising in the transport of liquid products by road, rail and sea. With more than 70 years of experience, Hoyer ensures the safe and efficient delivery of chemicals, food, gas and mineral oil using a diverse fleet of tank containers, tanker trucks, flexitanks and intermediate bulk containers (IBCs) [48]. Operating as a freight forwarder, Hoyer plays a crucial role in the logistics network by acting as a link in the supply chain, ensuring the efficient movement of goods. The position of Hoyer is schematically presented in Figure 4.1, which provides a simplified view of Hoyer's function as a freight forwarder for the overseas transport of tank containers. There is a supplier with a certain product who wants to transport its product and goes to Hoyer for this. Hoyer can transport this product by storing it in one of its containers. To transport this container overseas, Hoyer contracts a carrier. The carrier transports the container overseas to a destination port. The container is then unloaded from the carrier at the port of arrival and subsequently delivered to the customer. The customer removes the product from the container, after which Hoyer can clean the container and use it again, starting the process from the beginning.

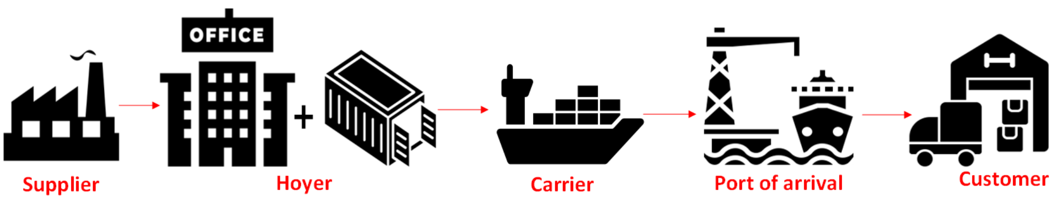


Figure 4.1: Schematic representation of Hoyer as freight forwarder

Within Hoyer, the business unit Hoyer Global Transport is responsible for the overseas transport of tank containers. Hoyer is committed to profit-driven operations while taking into account environmental and employee interests. Hoyer owns more than 40,000 tanks, more than 1,700 tankers and more than 55,000 IBCs [48]. It is important to know that the principle that one and the same tank container is suitable for all requirements does not apply in the transport of liquid products. Hoyer therefore offers a varied range of tank containers tailored to the different transport needs of liquids and gases [78].

Hoyer is currently facing significant challenges in selecting carriers for the overseas transport of tank containers. These challenges have led the company to switch from its usual 12-month tendering process to a 3-month tender period due to the current issues in the Red Sea. The requirements for carriers are influenced by Hoyer's profitability and sustainability goals, as well as the specific demands of their customers. To address these challenges and improve the efficiency and safety of their logistics services, there is a growing need for research into improving carrier selection processes. This research will help Hoyer to better navigate the complexities of the current logistics environment and meet both their internal goals and customer requirements effectively.

4.2. Stakeholders

Identifying key stakeholders is crucial for identifying the company's requirements. Through interviews and secondary data analysis, the stakeholders involved in Hoyer's carrier selection process are identified. To present this overview an organisation chart is made, shown in Figure 4.2. Of these internal stakeholders, some of them can be seen as decision-makers. In Figure 4.2, it can be seen that the ”Global Head of Procurement overseas” is the final decision-maker and that the ”Regional Procurement Managers” are the intermediate decision-makers. Besides, the ”Category Manager Ocean Freight” is responsible for the category management. This person oversees all information from the regions and reports this to the ”Global Head of Procurement overseas.”

- **Global Head of Procurement overseas:** The ultimately responsible person and thus the final decision-maker.
- **Category Manager Ocean Freight:** Responsible for receiving and facilitating feedback from the various regions and utilising this in a specific format to communicate with the carriers from a central perspective.
- **Regional Procurement Managers:** They are responsible for selecting carriers for their export volumes. They are the intermediate decision-makers.
- **Regional Procurement Teams:** They are responsible for the ”daily” procurement-related tasks.

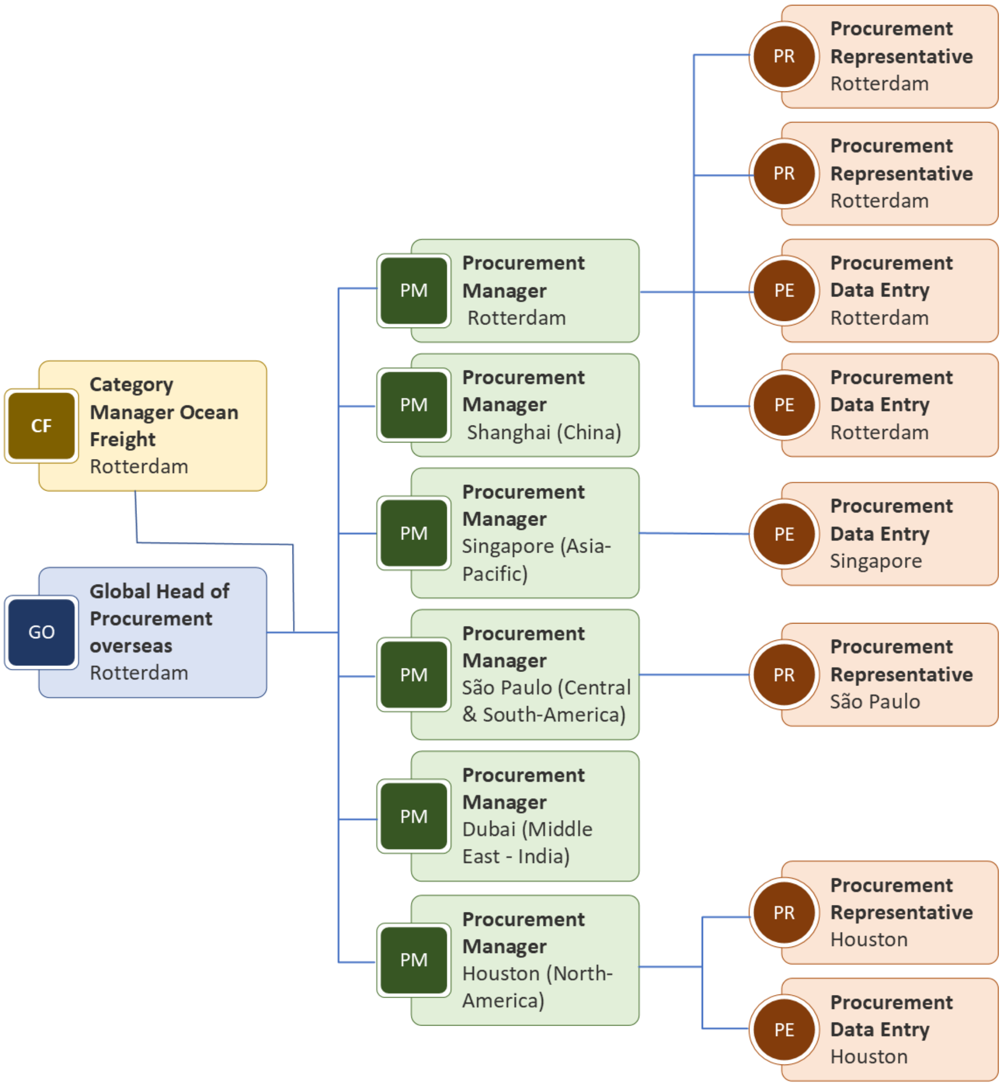


Figure 4.2: Stakeholder chart

In this research, only the "Global Head of Procurement Overseas," the "Category Manager Ocean Freight," and the "Procurement Manager Rotterdam" are considered. These three individuals significantly influence the selection process. Although other procurement managers also contribute, they are harder to reach, and some of the regions they represent are relatively small compared to the Rotterdam region. Moreover, in this study, the three decision-makers are considered equally important, despite any initial impressions from the Figure. It is crucial to recognise that all three stakeholders in the carrier selection process hold equal importance and have an equal voice, even if it may not appear so. This equal consideration is because all three decision-makers play a crucial role in selecting carriers. Each stakeholder influences the decision, making them all decision-makers. Additionally, they operate with the understanding that business expectations must be met, further justifying their equal say. Despite having varying degrees of influence at different stages of the tender, the "Global Head of Procurement overseas" ultimately makes decisions based on the trusted information provided by the other two decision-makers, showing their equal importance. Furthermore, the regional procurement managers have comprehensive insights into operational realities, enhancing their influence in the decision-making process. Although these stakeholders have the same level of importance, it is possible that they may prioritise certain factors differently. Therefore, these individuals are included as three individuals in this study where all three are equally important. This is important to consider when determining the weights of the criteria.

4.3. Contract types

Data on contract types is primarily collected through secondary data analysis. Hoyer provides a transport service for the overseas transport of tank containers, among other things. However, they provide this service under different types of contracts. When specifically looking at the overseas transport of tank containers. Hoyer has different scenarios of sea freight contracts. The three main scenarios are the Hoyer contract, customer contract and agent& Hoyer contract. In the first scenario, a customer places an order at Hoyer and Hoyer arranges the transport and contact with the carrier. In the second scenario, a customer also places an order at Hoyer and Hoyer arranges the transport but on behalf of the customer's contract. In the third scenario, a customer places an order with an agent and this agent processes the order on behalf of Hoyer. In this case, Hoyer is in contact with the carrier and the agent arranges the pick-up and delivery to the customer and container terminal. Hoyer mainly executes scenario one in sea freight contracts. This can also be seen in Figure 4.3. This Figure shows that the Hoyer contract scenario has been the most common over the years.

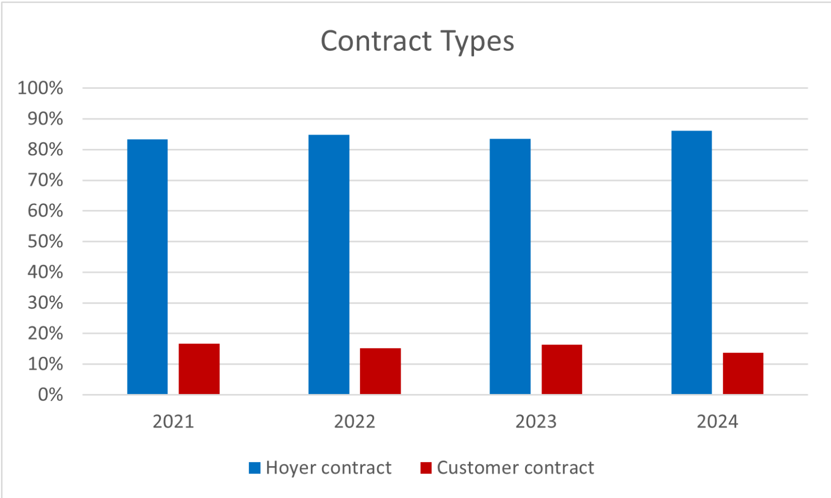


Figure 4.3: Contract types over the years

4.4. Types of containers and goods

As mentioned earlier, Hoyer offers a wide range of containers to accommodate different types of cargo, ensuring that customers can choose the most appropriate container for their specific transportation needs. These containers transport different types of goods, further explained in subsection 4.4.1. Besides, for some goods additional surcharge needs to be paid, which is discussed in subsection 4.4.2. By doing secondary data analysis more information is found on the types of containers and goods.

4.4.1. Container types

The two main types of containers that are being utilised by Hoyer are tank containers and flexitank containers. A tank container is specifically designed to transport liquids, gases, and powders in bulk. This container has a cylindrical shape in a frame and is typically constructed from stainless steel, ensuring its ability to endure the pressures and corrosive properties of the cargo it transports. A flexitank container, also referred to as a flexitank or flexibag, is a large and flexible container utilised for the transportation of large quantities of non-hazardous liquid goods. A flexitank container contains collapsible bags made of multi-layer materials such as polyethene or polypropylene and is a standard 20 Twenty-foot Equivalent Unit (TEU). Figure 4.4 gives an overview of the different types of containers over the past years. Important to note is that chemicals and food are both transported in a tank container. From this Figure, it can be concluded that tank containers are used most frequently and compromise the largest part of the business.

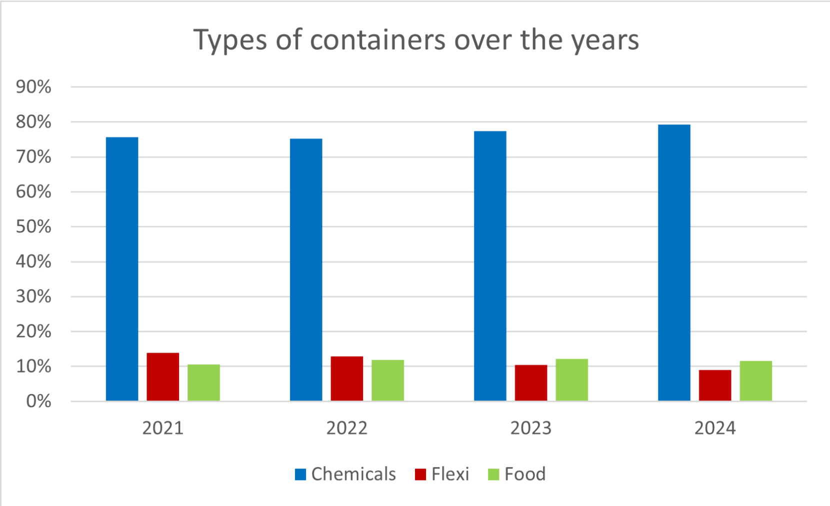


Figure 4.4: Overview container types over the years

4.4.2. IMO surcharge

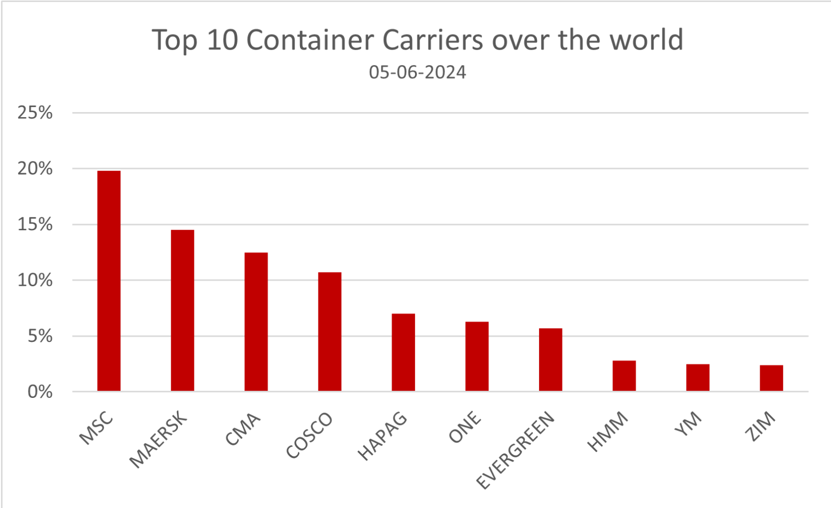
Dangerous liquid or gaseous goods are transported in tank containers. The International Maritime Organisation (IMO) is a specialised agency of the United Nations (UN) responsible for ensuring the safety and security of shipping, as well as preventing marine and atmospheric pollution caused by ships. The IMO's efforts contribute to achieving the UN's sustainable development goals [49]. Depending on the goods, an IMO surcharge may apply, which is an additional fee imposed by shipping companies to cover costs associated with complying with IMO regulations. Hoyer pays these surcharges to shipping companies, which use them to comply with IMO regulations. Although Hoyer initially covers these costs, they are usually passed on to customers. Hoyer can negotiate these surcharges, leading to variations between carriers. Therefore, it is important to consider these costs when selecting a carrier.

Nine main classes are used within the IMO, some of which still have sub-classes. Within the transport of containers overseas, Hoyer transports goods from various IMO classes [88]. Hoyer transports goods from all IMO classes except those that belong to IMO Class 1, 5 or 7. An overview of the various IMO classes is presented below.

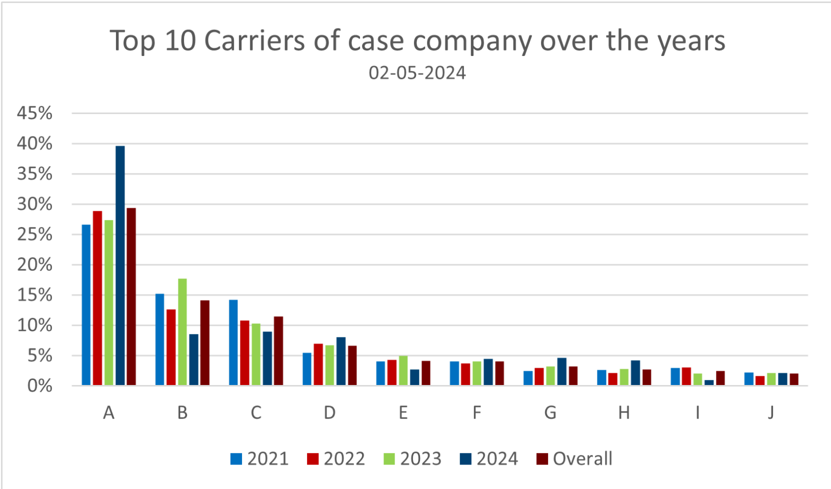
- IMO Class 1: Explosives
- IMO Class 2: Gases
- IMO Class 3: Flammable Liquids
- IMO Class 4: Flammable Solids or Substances
- IMO Class 5: Oxidising substances and organic peroxides
- IMO Class 6: Toxic Substances
- IMO Class 7: Radioactive material
- IMO Class 8: Corrosive substances
- IMO Class 9: Miscellaneous dangerous substances and articles

4.5. Carriers over the years

To transport its containers overseas, Hoyer pays a shipping company, also called a carrier, to move containers from one place to another. Hoyer purchases its carriers based on a tender process which will be explained later in section 4.7. By applying secondary data analysis, a comparison is made in the top ten carriers over the world presented in Figure 4.5a with the top ten carriers used by Hoyer, presented in Figure 4.5b, a comprehensive understanding of the broader industry dynamics and the specific operational requirements is gained [3]. Important to note is that the top ten carriers of Hoyer reflect the transportation of only tank containers under the Hoyer contract.



(a) Top ten container carriers over the world [3]



(b) Top ten carriers case company over the years

Figure 4.5: Overview of top ten carriers

From Figure 4.5 it can be seen that the distribution of container carriers globally is noticeably different from that of Hoyer's container carriers. On a global scale, there is a clear leading carrier, followed by several carriers with slightly smaller market shares. In contrast, within Hoyer's top 10 carriers, there is also a clear leading carrier, but a significant gap exists between the first and second carriers. The second and third carriers have relatively similar market shares, while beyond the fourth carrier, the market share of the remaining carriers has been relatively small over the years. This indicates that Hoyer predominantly conducts business with four major carriers, with one remaining the most preferred.

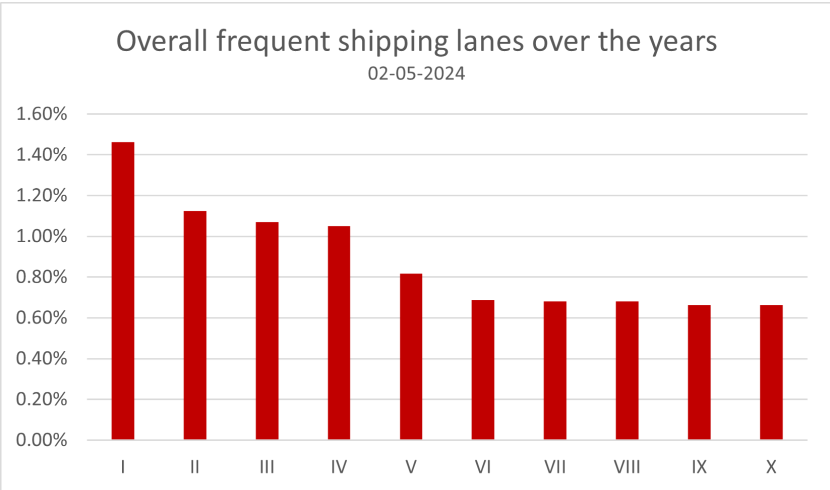
It was expected that there would be a difference between the top ten carriers worldwide and Hoyer's. In Figure 4.5a no distinction is made between container types. However, most shipping companies tend to be more difficult when it comes to transporting tank containers. Transporting tank containers involves more than transporting general containers. Tank containers require specific handling, and extra safety measures and are often very heavy, which makes them less attractive. In addition, the difference in carriers can also be explained by the fact that not every carrier offers a service for every shipping lane over which Hoyer wants to ship goods. For example, carrier A may offer a service for a shipping lane regularly used by Hoyer but for which no service is offered by other carriers.

4.6. Shipping lanes over the years

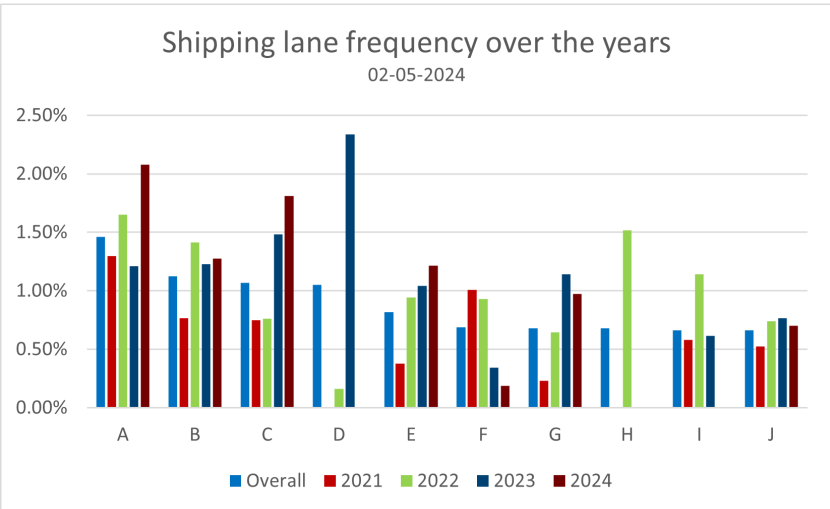
A carrier transports containers overseas from one place to another. This is also called a shipping lane. A shipping lane is a defined route regularly utilised by carriers for transporting goods between two or more ports or destinations. The distribution of shipping lanes could give insights into why certain carriers are chosen, making it interesting to further look into. Available data on shipping lanes is evaluated using secondary data analysis. First, the frequent shipping lanes, based on the number of occurrences, are discussed in subsection 4.6.1. Second, the most important shipping lanes, based on their occurrence and price, are discussed in subsection 4.6.2.

4.6.1. Frequent shipping lanes

From February 2021 until the beginning of May 2024 160,788 unique shipping lanes are utilised for the transportation of tank containers under the Hoyer contract. Figure 4.6a presents the top 10 shipping lanes of Hoyer over the years. This Figure is based on the sum of the occurrence of a shipping lane in the period from February 2021 until the beginning of May 2024. From this Figure, it can be concluded that the most frequent shipping lane over the years is shipping lane I, which is also referred to as shipping lane A in Figure 4.6b. The difference between this shipping lane and the second most frequent shipping lane II is approximately 0.34%. Hereafter the difference between the frequency of shipping lanes is rather lower or the same.



(a) Overall frequent shipping lanes over the years



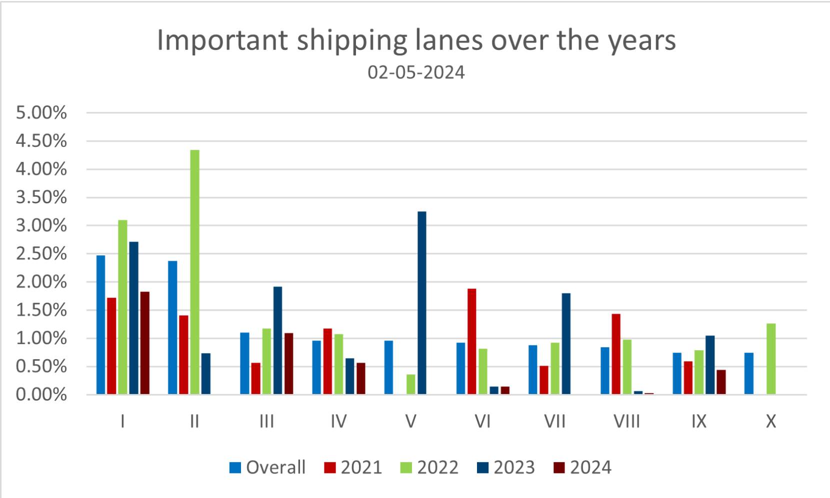
(b) Shipping lane frequency over the years

Figure 4.6: Frequency of shipping lanes

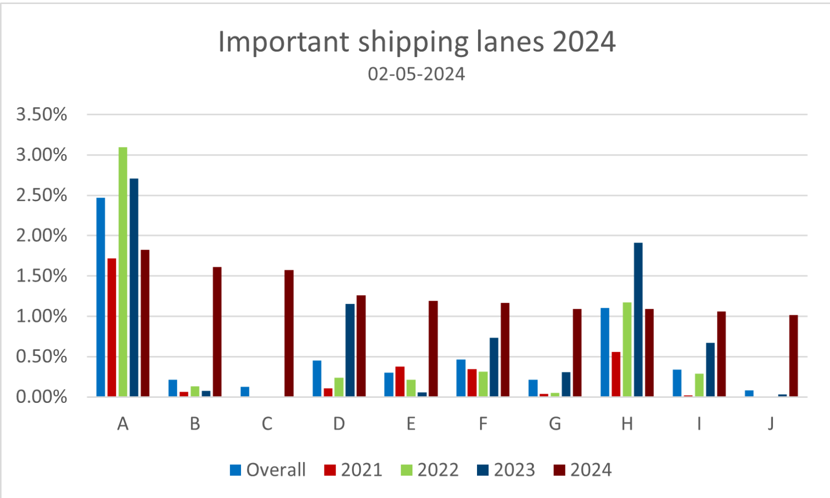
When looking at the occurrence of the shipping lanes per year in Figure 4.6b it is evident that the occurrence of a shipping lane is very variable per year. For example, shipping lane D has a large share in 2023 but no share in 2021. In addition, it can be seen that the share of a shipping lane, in both Figures, is very small, less than 2.5%. This is explained by the fact that Hoyer thus uses thousands of shipping lanes and that those Figures only reflect the top ten shipping lanes. Furthermore, the data reveals that only 3 shipping lanes are in the top ten most frequent shipping lanes every year. Shipping lane A has been in the first place over the past years, except for the year 2023. Moreover, there have been two other shipping lanes that are steadily present in the top 10 frequent shipping lanes over the years. These shipping lanes are B, which is II in Figure 4.6a and C, which is III in Figure 4.6a.

4.6.2. Important shipping lanes

The importance of a shipping lane is determined not only by its frequency but also by the average cost of transporting a tank container along that route. This cost significantly impacts the organisation's performance. Initially, the average cost of transporting a tank container under the Hoyer contract for each unique shipping lane over the years is calculated. Subsequently, these costs are multiplied by the corresponding number of occurrences of a shipping lane. The top ten shipping lanes with the highest costs times frequency over the years are presented in Figure 4.7.



(a) Important shipping lanes over the years



(b) Important shipping lanes 2024

Figure 4.7: Important shipping lanes

By looking at Figure 4.7 it is evident that the importance of shipping lanes varies significantly each year, and that the share of a shipping lane is again very small. From Figure 4.7a it is clear, that shipping lane I is overall the most important shipping lane. This shipping lane corresponds to shipping lanes I and A in Figure 4.7b. Furthermore, it is noted that some shipping lanes are very costly as many new shipping lanes entered the top ten.

When comparing these shipping lanes with the shipping lanes in subsection 4.6.1 it can be concluded, that the in subsection 4.6.1 mentioned shipping lanes A, B and C are currently the three most important shipping lanes. This is because those three shipping lanes are present in the top ten overall frequent shipping lanes and also in the top ten of price times frequency.

Furthermore, the distribution of shipping lanes does not necessarily explain why specific carriers are chosen. This is because the frequency of shipping lanes thus varies significantly over time, and the company also considers the combination of price and frequency, leading to varied outcomes. Additionally, each shipping lane typically has at least three different carriers providing services, and these carriers often change, adding further complexity to understanding carrier selection based solely on lane distribution.

4.7. Tender process

Hoyer selects its carriers based on a tender process which can be seen as the current decision-making process. To map out this tender process, interviews and secondary data analysis are utilised. These methods provide a detailed understanding of the steps involved in the tender process. During the tender, there are several responsibilities discussed in subsection 4.7.1. In addition, the tender always follows several steps elaborated in subsection 4.7.2. Finally, in subsection 4.7.3 other tender-related issues that are useful to know about are presented.

4.7.1. Responsibilities during the tender

Using a tender-based approach for overseas tank container carrier selection allows Hoyer to obtain competitive bids, negotiate favourable terms, and select carriers that best meet their specific requirements. Regular reviews and communication with the selected carriers help to maintain a successful long-term partnership. The global procurement team of Hoyer is responsible for the transport of overseas containers. This team serves from different regions around the world. These regions are Rotterdam, Dubai, Singapore, Shanghai, Houston and São Paulo, presented in Figure 4.8. These regions all have their regional procurement manager as shown in Figure 4.2. The regions are responsible for selecting carriers for their own export volume. For example, for a shipment from Antwerp to Houston, the procurement manager in Rotterdam is responsible for selecting a carrier and allocating volumes to a certain carrier. If the shipment was from Houston to Antwerp then the Houston region would handle the carrier selection and volume allocation. Additionally, the Global Head of Procurement Overseas is based in Rotterdam. Unlike previous tenders, this tender is being managed from Rotterdam, making the Rotterdam region the main contact point. However, other regions are still heavily involved, providing input on their preferred carriers. The Rotterdam region is also responsible for implementing the tender outcomes across all regions, ensuring a standardised approach. In previous tenders, each region handled this themselves.

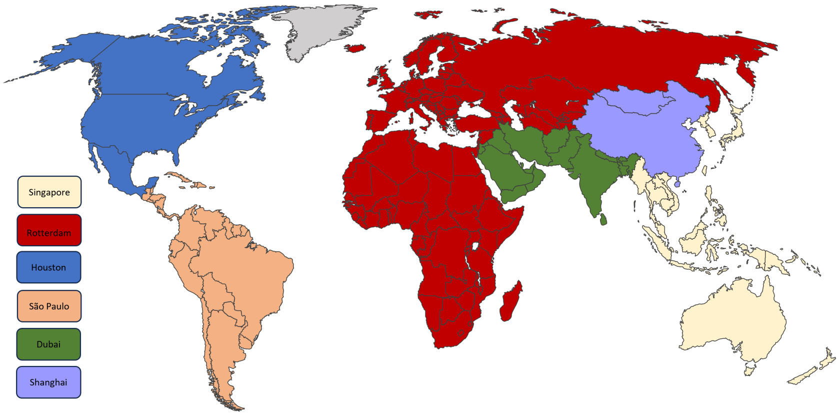


Figure 4.8: World map overview Hoyer regions

4.7.2. Steps in the tender process

The tender generally follows the steps that are shown in Figure 4.9. The process begins with identifying tender requirements, which shape the preferences. Regional procurement managers provide input, possibly with contributions from their regional sales, finance, and operations departments. Once the requirements are established, it becomes clear who to approach to participate in the tender. These potential carriers interpret the requirements and submit their initial bids. Next, Hoyer reviews and evaluates the bids. Following this, Hoyer comes with a challenging but explainable counteroffer. The carriers then submit their final bids, which Hoyer evaluates once more. Decisions are made and accepted based on these evaluations. Finally, if all conditions are met, a contract is offered at the end of the tender, and quantities are allocated for a specified period. A more detailed description of the tender process is presented in Appendix C. This Appendix includes a flowchart that details each step, specifying who is responsible and what information is used.

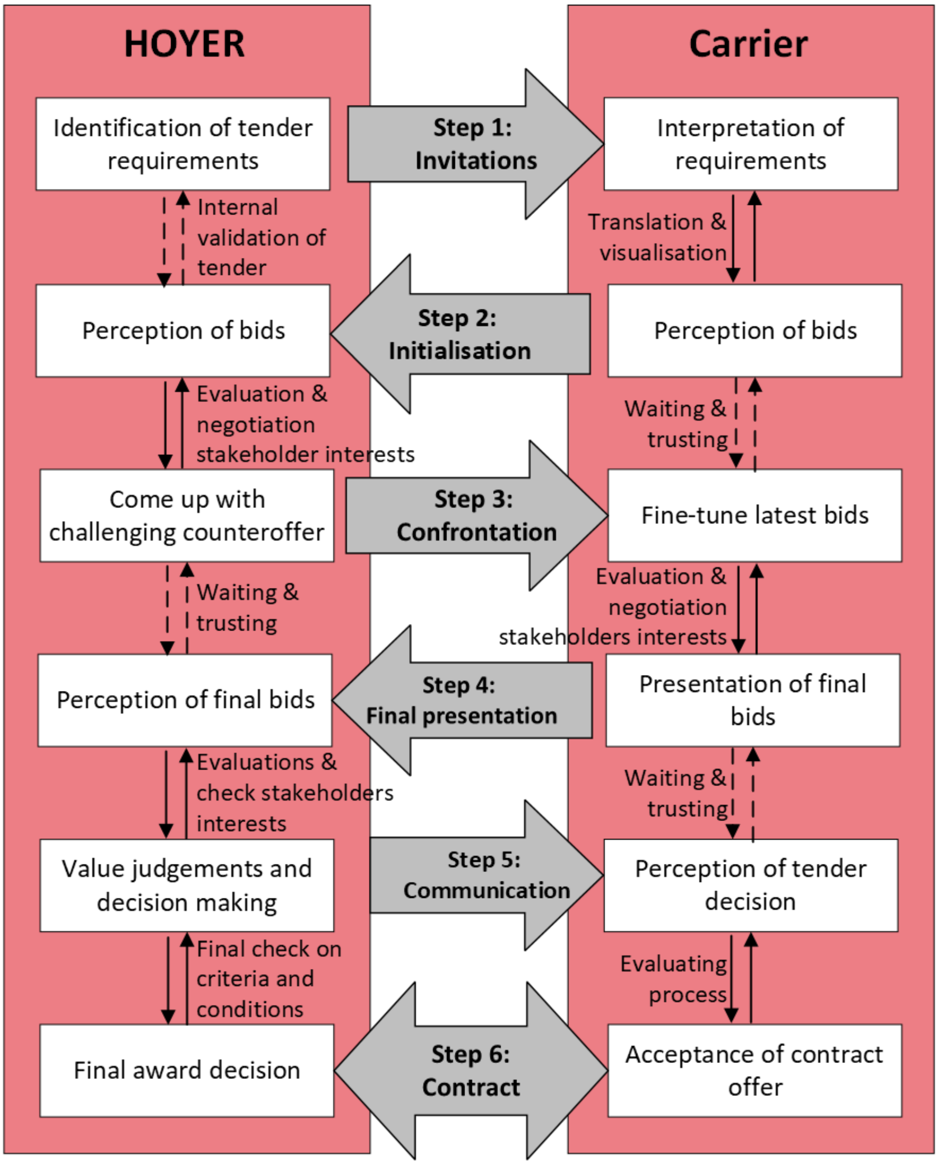


Figure 4.9: General tender process

4.7.3. Other tender specifications

After the tender is completed, several ongoing activities take place. For example, Quarterly Business Reviews (QBRs) are held with all selected carriers during the contract period. These meetings are conducted to discuss progress. Before each meeting, internal discussions are often held to review the financial, commercial, and operational aspects. With the carriers, overall performance is evaluated and potential improvements are addressed. The most recent tender, which concluded in late March, differed from previous ones. Unlike earlier tenders, this one was managed centrally from the Rotterdam office. Additionally, the new position of "Category Manager Ocean Freight" played a role in this tender, which was not the case previously. Including this position allowed for a centralised approach, as this role consolidated information from multiple carriers.

4.8. Current carrier selection

The current carrier selection is analysed with the use of interviews and secondary data analysis. In the latest tender, the company initially assessed the top three carriers for each shipping lane. For the major shipping lanes, those handling the transportation of over 50 TEUs, the company consistently selects two to three carriers to spread potential risks. The principle behind this strategy is to allocate 80% of the volume to the most favourable carrier for a particular shipping lane, with the remaining 20% designated for the second-ranked carrier. This methodology is specifically employed for the largest shipping lanes. However, for the smaller shipping lanes, where, for instance, only 5 TEUs are transported, typically only one carrier is selected.

For selecting carriers, the company uses specific criteria. In the ”Request For Proposal” (RFP) it is stated that the company currently employs four criteria for selecting its carriers. These criteria are listed below.

- *Service*
- *Transit-time*
- *Confirmed Allocation*
- *Price*

Furthermore, it is important to note that the company currently reports in its RFP to potential carriers that none of these criteria are given specific weight. For example, *Service* is not considered more important than *Transit-time*. However, in practice, the company does prioritise certain criteria during the selection process. *Price* is considered the most important criterion. When price differences between carriers are small, the company evaluates the differences in scores on the other criteria. Additionally, there are other factors, not explicitly listed as criteria, that influence the selection process. These factors, such as experience with a carrier or reliability of a carrier, are not directly visible but play a role in the final decision. These considerations, while not formally mentioned, do impact the choice of carrier.

4.8.1. Lexicographic ordering

From the above-mentioned information, it becomes clear that Hoyer implicitly uses lexicographic ordering to select its carriers. Lexicographic ordering is a non-compensatory decision-making method often used in MCDM [91]. The theory of lexicographic preferences was proposed by Georgescu-Roegen in 1954 and later expanded by Encarnacion Jr. in 1964 who studied lexicographic ordering [39, 28].

Lexicographic ordering evaluates alternatives based on one criterion at a time, beginning with the most important criterion. If the alternatives are identical according to the first criterion, the next criterion is considered, and this process continues until a difference is found. For example, if *Cost* is the most important criterion in choosing a carrier, carrier B would be chosen over carrier A if it has lower costs. However, if both carriers have the same cost, the next most important criterion is considered. This process continues with subsequent criteria until a difference is found that can determine the choice. If a significant difference is identified at any criterion, the remaining criteria will not be evaluated. Thus, the decision is made based on the first criterion where a notable difference is observed, reflecting the principles of lexicographic ordering [8].

4.9. Conclusion case study

The information in this chapter is based on currently available data focusing on the Rotterdam region of Hoyer, which is crucial for understanding the application of the methods. The methods used, including interviews and secondary data analysis, have provided a robust framework for how Hoyer evaluates and selects its carriers. Additionally, this chapter has identified Hoyer's requirements, which should be taken into account in the rest of the research to ensure improvements in carrier selection align with Hoyer's operational context and strategic goals.

Hoyer is a global leading logistics company specialising in the transport of liquids by road, rail, and sea. Multiple stakeholders are involved in selecting carriers, and this research includes three of them, each given equal consideration. Hoyer primarily operates under their own contract, using various containers, with tank containers being the most frequently used and comprising the largest portion of the business. Depending on the contents of a tank container, a certain *IMO Surcharge* needs to be paid, varying between carriers. Hoyer has consistently used one carrier the most often over the past few years. The three most important shipping lanes are identified as A, B, and C. The tender process, a critical aspect of carrier selection, underscores Hoyer's commitment to competitive bidding, current evaluation, and other specifications. For selecting a carrier, four criteria are currently in place: *Service*, *Transit-time*, *Confirmed Allocation*, and *Price*, with *Price* being the primary criterion. Other factors like carrier experience and reliability also influence the selection process, even though they are not explicitly listed as criteria.

Based on the information presented in this chapter, the MCDM tool will be applied to enhance Hoyer's carrier selection process. The company's requirements lay the foundation for identifying and selecting the criteria, ensuring that the MCDM tool aligns with Hoyer's needs. These requirements are considered as criteria to be included in the BWM. Additionally, only carriers previously used by Hoyer will be sourced and included as alternatives, ensuring consistency and reliability. Furthermore, performance matrices will be established for the three most important shipping lanes, identified as A, B, and C. Subsequently, TOPSIS will be employed to evaluate the carriers that offer service on these three shipping lanes. The results from applying the MCDM tool to Hoyer's context are presented and discussed in the next chapter.

5 Results

This chapter first addresses the criteria identified and selected for MCDM. Subsequently, the weights of these criteria are presented. Following this, the carriers that are sourced are elaborated upon. Then, the established performance matrices are presented. Thereafter, the results of applying TOPSIS are outlined. Further, sensitivity analyses are performed, followed by verification and validation. Finally, a conclusion of the chapter is provided.

5.1. Identified and selected criteria for MCDM

In this section, all criteria for the MCDM are identified first. Thereafter, the selection of the criteria and the final selected criteria are presented. Appendix D gives a detailed description of all identified criteria and the selection of criteria.

5.1.1. Identified criteria

As mentioned in section 2.2, many criteria for carrier selection are already known in the literature. However, sustainability criteria are not widely included. To address this, a broader literature review and interviews are conducted to identify more sustainability criteria. Additionally, the interviews, which are reported in Appendix B, reveal other important criteria to consider when selecting carriers.

From the literature review and the interviews, a large number of criteria are identified. However, some criteria are found to overlap or are already clearly accounted for by another criterion and are therefore excluded. In the end, a list of 34 criteria is conducted. As this list is very long, the criteria have been subdivided into three groups. These three groups are based on what sustainability encompasses, namely: economic, social and environmental factors as mentioned in section 2.3. Besides, criteria that are found in the literature are often already subdivided within one of those groups. Therefore, it is chosen to use these groups as categories for the criteria. The list of the 34 identified criteria and their definitions can be found in Table D.1 in Appendix D.

5.1.2. Selected criteria

To perform BWM, a list of 34 criteria is too long. Managing a list of 34 criteria for BWM is challenging because the extensive number of criteria complicates the evaluation process. Each criterion must be assessed and compared, increasing the complexity and potential for oversight errors. Additionally, the interdependence and relative impacts of each criterion become harder to measure accurately, making it difficult for the company to ensure comprehensive and balanced decision-making. This extensive list reduces focus and can lead to decision fatigue, reducing the overall effectiveness of the evaluation process.

Therefore it is chosen to further limit the number of criteria that are presented in Table D.1. This is done with the help of the three decision-makers involved in selecting carriers within the company also mentioned in section 4.2. These three decision-makers are asked to complete a survey. This survey contains all the criteria from Table D.1. Subsequently, the decision-makers are asked to indicate whether a criterion should be *Included*, *Maybe Included* or *Not Included* when selecting a carrier. Since it is established that the decision-makers can influence each other's choices, the decision-makers independently completed this survey. In Appendix D a more detailed description of the content of the survey and its detailed results is given.

For the selection of the criteria, it is decided to adhere to the three categories, economic, social, and environmental, into which the criteria are divided as the list of criteria remains extensive. Furthermore, during selection, four exceptions are made based on the interviews and survey results. Despite the survey indicating that the *Past Performance* of a carrier was unimportant, it is included due to the final decision-maker's input. The criterion *Fuel Type* is added due to its frequent mention in literature and interviews. In addition, the criterion *ETS Fee* is moved to the environmental category since it addresses environmental concerns. Lastly, the criterion *Transshipment Port* is excluded to avoid double counting, as it is already covered by the criterion *Service*. The criteria that are selected for inclusion in this research are presented in Table 5.1.

Table 5.1: Selected criteria

Category	Criterion	Definition
Economic	**C1:** Service	The number of ports of call a carrier uses to transport a tank container.
	C2: Rate Validity	The period for which the agreed transport rates are valid.
	C3: Transit-time	The time a carrier needs to move goods from origin to destination, covering the entire journey including any delays or layovers.
	C4: Confirmed Allocation	The guaranteed space for cargo on the transport vessel.
	C5: Price	The cost of the transport service.
	C6: IMO Surcharge	The extra fee imposed by carriers for transporting goods classified as dangerous by the International Maritime Organisation. It is negotiable.
	C7: Past Performance	The amount of volume a carrier is currently transporting compared to the awarded volume to that carrier.
Social	**C8:** Work safety	Prevention of workplace accidents and ensuring a secure work environment through safety protocols, equipment, and training.
	C9: Labour Health	The well-being of employees, encompassing physical and mental aspects. It involves ensuring safe working conditions and promoting a positive work environment.
	C10: Respect for ethical issues and legal compliance	The commitment of a carrier to moral principles and adherence to laws and regulations.
	C11: Employee interests and rights	Consideration for the rights and interests of employees.
Environmental	**C12:** CO_2 Emission per Shipment	The amount of carbon dioxide emitted during transportation.
	C13: Compliance with sustainability regulations	Adherence to environmental sustainability laws and regulations.
	C14: Fuel Type	The type of fuel used by the transport. It involves considering cleaner and renewable fuel sources to minimise environmental impact and meet emission regulations, promoting sustainability in maritime transport.
	C15: ETS Fee	A charge imposed by carriers to comply with the Emissions Trading Systems (ETS), aiming to reduce greenhouse gas emissions. It reflects the carrier's costs for carbon allowances or offsets.

5.2. Criteria weights

Now that the decision criteria are established, a weight is assigned to each criterion using the Best-Worst Method (BWM). This involves performing pairwise comparisons and then aggregating these weights to determine a single weight for each category and criterion. From this process, the final weights are calculated.

5.2.1. Best-Worst Method (BWM)

The Best-Worst Method, founded by Rezaei [79], is utilised to determine the weights of the criteria presented in Table 5.1. When there are more than 9 criteria, it is recommended to cluster the criteria into several clusters for BWM. This way, one level of hierarchy is added to the the problem. The clusters that are used are the same as the categories: economic, social and environmental.

5.2.1.1. Pairwise Comparisons

Because of the added hierarchy, four analyses are performed. The analyses and what factors are included in each analysis are shown below.

Analysis 1
{*Economic*(c_1), *Social*(c_2), *Environmental*(c_3)}

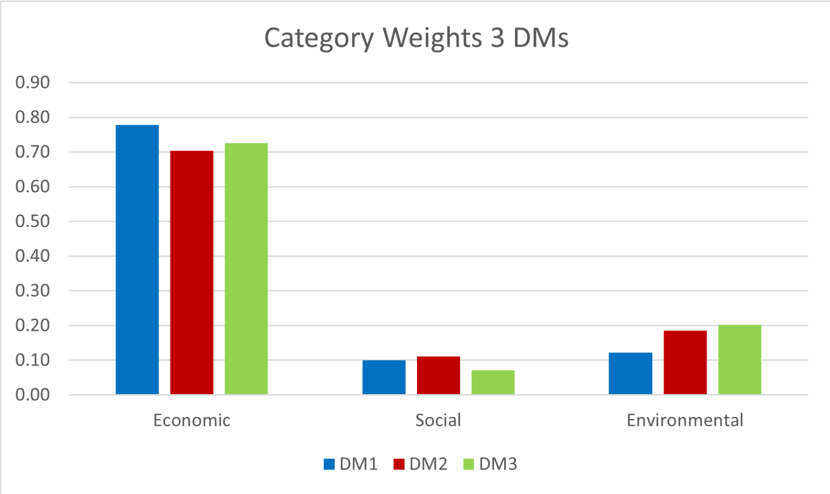
Analysis 2
{*Service*(c_1), *Rate Validity*(c_2), *Transit-time*(c_3), *Confirmed Allocation*(c_4), *Price*(c_5),
IMO Surcharge(c_6), *Past Performance*$(c_7$}

Analysis 3
{*Work Safety*(c_1), *Labour Health*(c_2), *Respect for ethical issues and legal compliance*(c_3),
Employee interests and rights(c_4)}

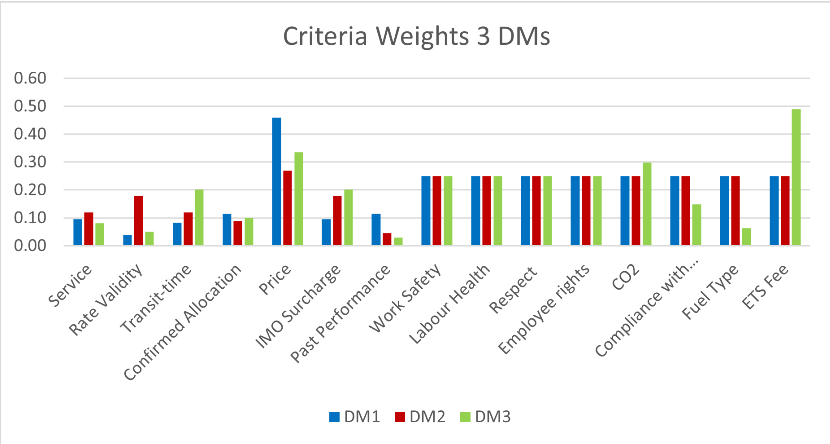
Analysis 4
{CO_2 *Emission per Shipment*(c_1), *Compliance with sustainability regulations*(c_2), *Fuel type*(c_3),
ETS Fee(c_4)}

Each analysis requires two sets of pairwise comparisons to be performed by each decision-maker. For this purpose, a survey is sent to the same three decision-makers as for the criteria selection, because these experts are the decision-makers. Again, the decision-makers are chosen to complete the survey independently of each other to avoid possible influence from each other. The survey first focuses on the categories and then on the criteria within those categories. At the beginning of each analysis section, the decision-maker has to determine the best and the worst criterion (or category). Subsequently, two sets of pairwise comparisons are filled in per analysis by each decision-maker. This is done by asking the decision-makers to express their preference for *"the Best criterion over all the other criteria"*, and then their preference of *"all the other criteria over the Worst"* by selecting a number between 1 and 9. The meaning of those numbers is presented in section 3.7.

In the end, each analysis involved pairwise comparisons of three decision-makers. For each comparison, the consistency ratio is checked and discussed with the respondent. This is done to come to more reliable data, deeper insights and to get a better understanding of the preferences of the respondents. Ultimately, these pairwise comparisons lead to a weight for each category and a weight for each criterion within a category. Consequently, three weights are obtained for each category and three weights for each criterion. The comprehensive results of the pairwise comparisons are presented in section E.1. An overview of the weights that follow from those pairwise comparisons per decision-maker can be seen in Figure 5.1.



(a) Category weights of three DMs



(b) Criteria weights of three DMs

Figure 5.1: Overview weights three DMs

From Figure 5.1a, it is evident that all three decision-makers assign nearly identical weights to each category. It is worth noting that the company highly values social criteria. However, since carriers often have high standards for these criteria, the company assumes they will be met and has therefore assigned them lower weight. Consequently, more importance is placed on other categories. DM1 (Decision-Maker 1) clearly considers the economic category the most important, while DM2 and DM3 place slightly more emphasis on the environmental category. Additionally, DM3 assigns the least weight to the social category but the most to the environmental category. It can thus be concluded that there is a consensus among the decision-makers regarding the importance of the categories. The economic category can be seen as the most important category.

By looking at Figure 5.1b, more differences between the three DMs can be seen. The three decision-makers show different priorities in terms of criteria weighting. DM1 clearly favours *Price*, has average regard for social and environmental considerations and assigns different importance to other economic criteria, especially *Rate Validity* and *Past Performance*. In contrast, DM2 and DM3 attach slightly less importance to *Price*. DM2 emphasises the importance of *Rate Validity*, while DM3 places more emphasis on the criterion *Transit-time*. Furthermore, DM2, like DM1, also gives equal weight to all criteria in the social and environmental categories. In contrast, while DM3 gives equal weights to all social criteria, this decision-maker clearly considers the criterion *ETS Fee* to be much more important than all other environmental criteria.

In summary, while all three decision-makers show similar weighting for social criteria overall, DM3 stands out by giving different importance to environmental criteria. DM3 thinks that *ETS Fee* is way more important than other environmental criteria. In addition, *Price* is most important for all three DMs, but differences appear in how they weigh other economic criteria: DM1 values *Past Performance*, DM2 emphasises *Rate Validity*, and DM3 highlights *Transit-time*. Important to mention is that although the differences between the DMs are not very large, they are important to take into account. So in case there will be only one decision-maker in the future, slightly different results could be expected.

5.2.2. Aggregating BWM weights

From the pairwise comparisons, multiple weights for each category and each criterion are found as shown in Figure 5.1. The weights are aggregated using the Geometric mean method to come to one weight for each category and each criterion based on the input of all the decision-makers [83]. This method is chosen because it is well-suited for aggregating weights when only a few decision-makers are involved. Besides, its simplicity and ease of use make it attractive to utilise. Furthermore, it combines the input of the decision-makers while maintaining their relative importance. Lastly, the mathematical robustness ensures an accurate reflection of shared preferences and minimises the impact of outliers, making it a practical and dependable approach for small decision-making groups.

5.2.2.1. Geometric Mean

In mathematical terms, the geometric mean represents a measure of central tendency for a finite set of real numbers by considering the product of their values. It is calculated as the *n*th root of the product of *n* numbers [71]. For a set of numbers $w_1, w_2, \ldots, w_n$ the geometric mean is expressed as:

For each criterion, the geometric mean is calculated by the following formula.

$$G_i = \sqrt[n]{\Pi w_j} = \sqrt[n]{w_1 \times w_2 \ldots w_n} \tag{5.1}$$

Where:

- G_i = Geometric mean of criterion i
- Π = Product of weights
- w_j = Weight of decision-maker j
- n = Total number of decision-makers

This results in a weight per criterion, but the sum of these weights does not add up to 1.

$$\sum G_i \neq 1 \tag{5.2}$$

To obtain the correct weights for each criterion, the final step is to divide the geometric mean of each criterion by the sum of the geometric means of all criteria. Following this, the weights for each criterion should sum up to 1.

After calculating the geometric mean G_i for each set of numbers $w_{j1}, w_{j2}, \ldots, w_{jn}$, the sum of all geometric means is calculated S:

$$S = G_1 + G_2 + \ldots + G_i \tag{5.3}$$

Finally, to obtain the normalised geometric mean NG_i, each geometric mean G_i is divided by the sum of all geometric means S:

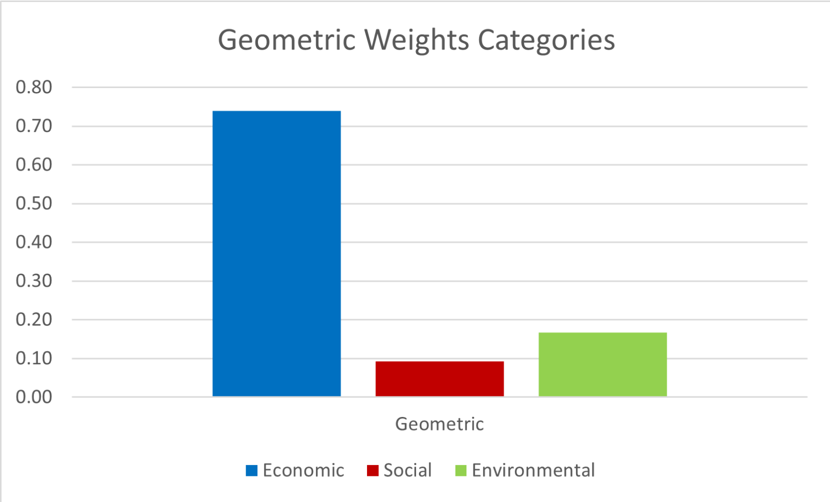
$$NG_i = \frac{G_i}{S} \tag{5.4}$$

This normalisation ensures that the resulting values represent proportions of the total, allowing for comparison or aggregation across different sets of numbers.

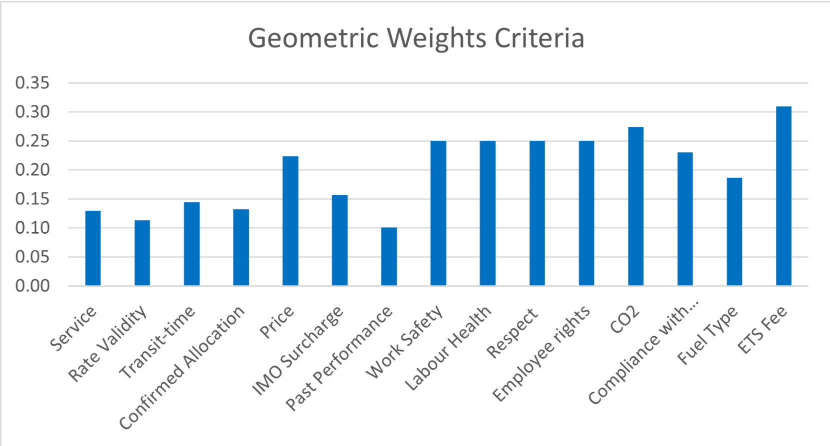
The sum of the normalised geometric means NG_i should sum up to 1.

$$\sum NG_i = 1 \tag{5.5}$$

The weights that are calculated with the geometric mean method are presented in Figure 5.2 on the next page.



(a) Geometric weights categories



(b) Geometric weights criteria

Figure 5.2: Overview geometric weights

From Figure 5.2a, it can be seen that the economic category is much more important than the other two categories. Specifically, the economic category is nearly eight times more important than the social category and over four times more important than the environmental category. Moreover, the social and environmental categories show similar levels of importance, with the environmental category slightly ahead. However, when directly compared, the environmental category appears almost twice as important as social. Furthermore, from Figure 5.2b it can be seen that *Price* is the most important economic criterion, all social criteria are of equal importance and CO_2 *Emission per Shipment* and *ETS Fee* are the most important environmental criteria.

5.2.3. Final criteria weights

To arrive at the final weights, where each criterion has a single weight rather than separate weights for categories and criteria, the criterion weight is multiplied by its corresponding category weight. For example, the criterion weight for *Price* is multiplied by the category weight economic. This process is repeated for all criteria. The sum of all the criteria weights must sum up to 1. The final weights of all the criteria are presented in Figure 5.3.

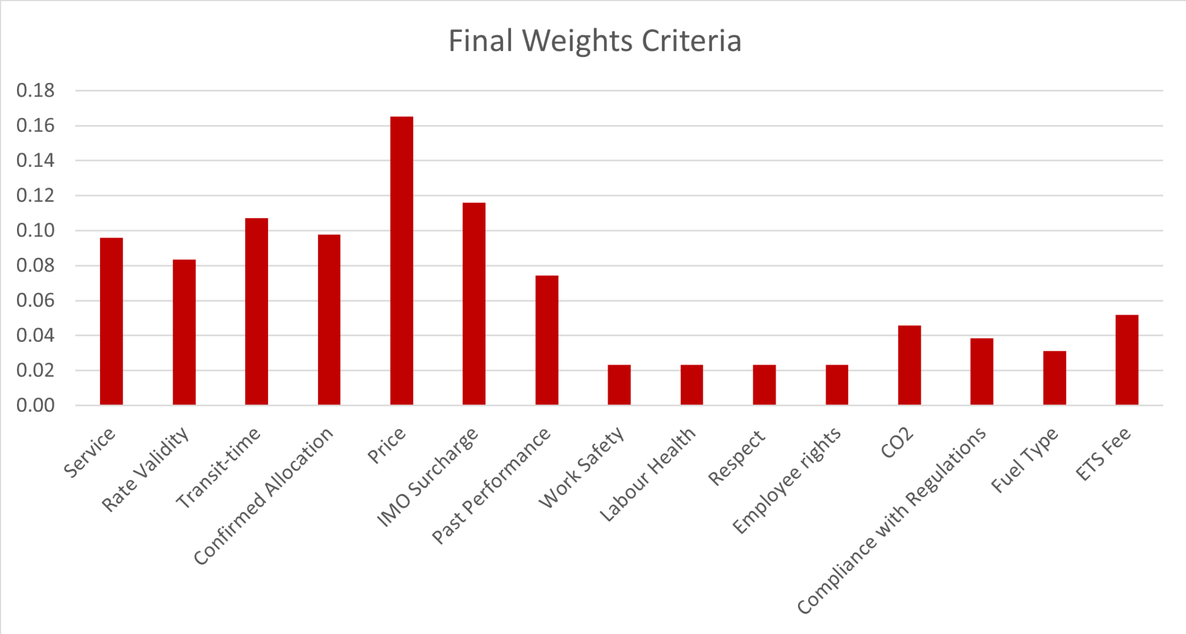


Figure 5.3: Final weights of all criteria

From Figure 5.3, it can be seen that the economic criteria are much more important than the social and environmental criteria. This is expected due to the substantial weight assigned to the economic category. Notably, the environmental criteria are given more importance than the social criteria. Although the company highly values social criteria, carriers often meet high standards for these criteria. Therefore, the company assumes they will be met and has assigned them lower weight, placing more importance on other criteria instead.

Additionally, it is apparent that *Price* is the most important criterion, followed by *IMO Surcharge* and *Transit-time*. Furthermore, all economic criteria outweigh both social and environmental criteria. Moreover, all social criteria are generally equally important to each other. However, environmental criteria vary, with CO_2 *Emission per Shipment* and *ETS Fee* being the most crucial and closely ranked.

Given that *Price* is significantly more important than other criteria, it is insightful to assess its relative importance. Compared to other economic criteria, it is one and a half to two times more important. When comparing it to social criteria, it is almost five times as important, and concerning environmental criteria, it ranges from over two times to five times more important than *Fuel Type*.

Based on the findings mentioned above, it becomes clear that economic considerations such as *Price* and *IMO Surcharge* play an important role in economic criteria in decision making. Further, despite the company's strong emphasis on social criteria, it appears that these factors appear to have less influence on final decisions. Moreover, certain environmental criteria, notably CO_2 *Emission per Shipment* and *ETS Fee*, emerge as particularly important. This shows the need for specific strategies to effectively tackle these environmental issues. Finally, the focus on *Price*, especially compared to social and environmental criteria, highlights the high importance of cost efficiency in decision-making processes.

In Table E.5 in Appendix E a comprehensive overview can be found of the weights per criterion per decision-maker, as well as the final geometric weights and a ranking of the criteria based on the geometric weights.

5.3. Sourced Carriers

As mentioned in section 3.2 in parallel with BWM carriers are sourced. Three shipping lanes are chosen to be evaluated since evaluating more shipping lanes is not feasible in the limited time of this research. The three shipping lanes that are chosen are the shipping lanes A, B and C. These three shipping lanes are chosen because subsection 4.6.2 shows that these shipping lanes have been very important over the years. Furthermore, there are at least four different carriers offering service on all three of these shipping lanes. Shipping lanes A and B have both six available while shipping lane C has four carriers.

Now that all the carriers are known for each shipping lane their scores on each criterion can be sourced. However, before doing that some criteria require quantification as they are not directly clear on how they are measured. The values of the criteria must adhere to an interval or ratio scale for analysis. During quantification, each criterion is assigned a specific value that represents the performance of a carrier. For instance, in *Service*, the number of ports of call reflects efficiency. In contrast, *Past Performance* is determined objectively by assessing the volume of cargo transported by each carrier compared to the volume awarded to them. Similarly, in the social category, criteria like *Work Safety* and *Compliance with ethical standards* are quantified based on sustainability reports of the carriers. Lastly, in the environmental category, criteria such as CO_2 *Emission per Shipment* and *Compliance with sustainability regulations* are also quantified. These quantifications ensure a systematic approach to evaluating criteria, enabling informed decision-making in selecting carriers. An overview of the quantification of the criteria and their corresponding units is presented in Table 5.2. This Table also includes a column "Direction." This column is already added as this indicates whether a high (plus) or low (minus) value is preferred for a certain criterion. This is necessary for the TOPSIS evaluation but is included here for clarification. From the business and the company's customers' point of view, a low *Transit-time* is preferred but from the procurement point of view, a high *Transit-time* is preferred. Since the company's customers pay a rental price for each day. However, after a discussion with experts, it is chosen that a low*Transit-time* is preferred as a higher *Transit-time* is not that much preferred by procurement. A more comprehensive explanation of the quantification of each criterion is discussed in Appendix F.

Table 5.2: Quantified list of criteria

Category	Criterion	Unit	Direction
Economic	**C1:** Service	Ports of call (#)	-
	C2: Rate Validity	Months (#)	+
	C3: Transit-time	Days (#)	-
	C4: Confirmed Allocation	TEU (#)	+
	C5: Price	Dollar ($)	-
	C6: IMO Surcharge	Dollar ($)	-
	C7: Past Performance	Average awarded volume transported (%)	+
Social	**C8:** Work Safety	Fatalities (#)	-
	C9: Labour Health	LTIFR (#Incidents/Hour)	-
	C10: Respect for ethical issues and legal compliance	Completed Code (%)	+
	C11: Employee interests and rights	Completed training (%)	+
Environmental	**C12:** CO_2 Emission per Shipment	CO_2 (tons)	-
	C13: Compliance with sustainability regulations	Proportion of target met (%)	+
	C14: Fuel Type	EEOI (gCO_2/TEUkm)	-
	C15: ETS Fee	Dollar ($)	-

Now that the criteria, their weights and the carriers with their scores on the carriers are sourced, the performance matrices can be established and presented in the next section.

5.4. Established performance matrices

Based on the previously provided information the performance matrices for all three shipping lanes are created. The scores in the performance matrices are based on real input data from the past tender collected by the company and currently available information. For example, the input data for the criterion of *Past Performance* (C_7) is based on the current performance of carriers. The performance matrices of the three shipping lanes are presented below.

5.4.1. Performance matrix - Shipping lane A

Six carriers offer a service for shipping lane A. All these carriers have different scores for the criteria, except for the criterion *Confirmed Allocation* (C_4), as can be seen in Table 5.3.

Table 5.3: Performance matrix - Shipping lane A

	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}	w_{11}	w_{12}	w_{13}	w_{14}	w_{15}
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
A1	7	3	24	85	1233	50	14	2	0.72	90	98	1.15	50.00	61.40	46
B1	7	3	13	85	1492	200	48	0	0.00	96	100	1.00	40.00	58.40	42
C1	7	3	25	85	1435	100	27	0	1.47	89	89	0.48	61.98	38.20	35
D1	5	6	21	85	925	100	33	0	1.13	93	86	0.91	40.00	70.59	25
E1	5	3	23	85	1539	200	41	4	0.93	80	80	0.81	33.50	27.30	38
F1	5	12	21	85	1490	75	14	0	0.37	100	99	1.09	58.50	41.64	0

5.4.2. Performance matrix - Shipping lane B

The performance matrix for shipping lane B is presented in Table 5.4. Again, six carriers offer a service for this shipping lane. It can be seen that there are once more differences in scores on the criteria. However, for this shipping lane not only the scores for C_4 are the same, but also the scores for the criterion *ETS Fee* (C_{15}).

Table 5.4: Performance matrix - Shipping lane B

	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}	w_{11}	w_{12}	w_{13}	w_{14}	w_{15}
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
A2	4	3	30	114	394	50	14	2	0.72	90	98	1.63	50	61.40	1
B2	3	6	21	114	268	100	33	0	1.13	93	86	1.31	40	70.59	1
C2	3	3	23	114	292	75	25	9	0.93	92	90	1.31	39.90	24.10	1
D2	4	3	23	114	793	100	41	4	0.93	80	80	1.07	33.50	27.30	1
E2	4	12	22	114	745	300	14	0	0.37	100	98.80	0.66	58.50	41.64	1
F2	4	12	21	114	590	100	75	0	1.34	90	90	1.90	33	83.02	1

5.4.3. Performance matrix - Shipping lane C

The performance matrix for shipping lane C is presented in Table 5.5. It can be seen that there are large differences in the criterion *Price* (C_5) between the carriers. Furthermore, the scores on the criterion *Confirmed Allocation* (C_4) are the same again.

Table 5.5: Performance matrix - Shipping lane C

	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}	w_{11}	w_{12}	w_{13}	w_{14}	w_{15}
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
A3	2	3	19	138	1065	50	14	2	0.72	90	98	0.88	50	61.40	26
B3	1	6	14	138	801	100	33	0	1.13	93	86	0.86	40	70.59	17
C3	3	3	25	138	1123	200	41	4	0.93	80	80	0.76	33.50	27.30	17
D3	1	12	13	138	784	300	14	0	0.37	100	98.80	0.93	58.50	41.64	30

5.5. TOPSIS

Following the performance matrices, TOPSIS is applied to evaluate the multiple carriers that offer a service on a shipping lane. For each shipping lane the normalised performance matrix, the weighted normalised performance matrix and the final evaluation with the performance scores are presented. Within the final evaluation Tables also the company evaluation is given. The company evaluation is based on how they evaluated the carriers in the last tender. The goal is not to have the exact same evaluation as the company evaluation but it helps in interpreting the differences.

Additionally, a comparison of costs is provided based on the TOPSIS evaluation. Therefore, it is good to consider that the company typically only nominates a number one and two carriers, occasionally extending to a third choice, as discussed in section 4.8. To make a comparison in costs, 100 TEUs are assumed to be shipped over a shipping lane. The most preferred carrier, so the number one, therefore, carries 80 TEU. This corresponds to the 80% as mentioned in section 4.8. The number two thus transports 20 TEU (20%). From the company's perspective, the total cost is the sum of the *Price*, the *IMO Surcharge*, and the *ETS Fee*. Therefore, this aggregate cost is used for comparison of the costs. To determine the overall cost, the cost of shipping 80 TEU with the top carrier is combined with the cost of shipping 20 TEU with the second carrier. Subsequently, these combined costs are subtracted from each other to identify the additional cost for 100 TEU. Dividing this additional cost by 100 provides the incremental cost per TEU. Below the results per shipping lane are presented and discussed.

5.5.1. TOPSIS - Shipping lane A

From the performance matrix in Table 5.3 a normalised performance matrix is created, presented in Table 5.6. This normalised performance matrix is crucial for standardising data and helping to compare and maintain accurate evaluations. Since the criteria have different units and scales, normalising them ensures that each criterion carries equal weight, avoiding bias from criteria with a larger numerical range.

Table 5.6: Normalised performance matrix - Shipping lane A

	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}	w_{11}	w_{12}	w_{13}	w_{14}	w_{15}
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
A1	0.47	0.20	0.46	0.41	0.37	0.15	0.18	0.45	0.32	0.40	0.43	0.50	0.42	0.48	0.54
B1	0.47	0.20	0.25	0.41	0.44	0.61	0.61	0.00	0.00	0.43	0.44	0.44	0.34	0.46	0.50
C1	0.47	0.20	0.47	0.41	0.43	0.30	0.34	0.00	0.66	0.40	0.39	0.21	0.52	0.30	0.41
D1	0.34	0.41	0.40	0.41	0.28	0.30	0.42	0.00	0.51	0.41	0.38	0.40	0.34	0.56	0.30
E1	0.34	0.20	0.44	0.41	0.46	0.61	0.52	0.89	0.42	0.36	0.35	0.35	0.28	0.21	0.45
F1	0.34	0.82	0.40	0.41	0.44	0.23	0.18	0.00	0.17	0.45	0.44	0.48	0.49	0.33	0.00

From this normalised performance matrix, the weighted normalised performance matrix is created and presented in Table 5.7.

Table 5.7: Weighted Normalised Performance Matrix - Shipping lane A

	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}	w_{11}	w_{12}	w_{13}	w_{14}	w_{15}
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
A1	0.045	0.017	0.049	0.040	0.061	0.018	0.013	0.010	0.008	0.009	0.010	0.023	0.016	0.015	0.028
B1	0.045	0.017	0.026	0.040	0.074	0.071	0.045	0.000	0.000	0.010	0.010	0.020	0.013	0.014	0.026
C1	0.045	0.017	0.051	0.040	0.071	0.035	0.025	0.000	0.015	0.009	0.009	0.010	0.020	0.009	0.021
D1	0.032	0.034	0.043	0.040	0.046	0.035	0.031	0.000	0.012	0.010	0.009	0.018	0.013	0.017	0.015
E1	0.032	0.017	0.047	0.040	0.076	0.071	0.039	0.021	0.010	0.008	0.008	0.016	0.011	0.007	0.023
F1	0.032	0.068	0.043	0.040	0.073	0.026	0.013	0.000	0.004	0.010	0.010	0.022	0.019	0.010	0.000

Hereafter, the ideal best and ideal worst carriers on each criterion are determined. For example, in C_3 carrier B1 is selected as the ideal best, since a lower *Transit-time* is preferred mentioned in Table 5.2 and carrier C1 as the ideal worst. From here the Euclidean distances to the ideal best and ideal worst carriers are calculated for each carrier. Finally, the performance scores are calculated based on which the evaluation is made, where a high score equals a good evaluation. The performance scores and the final evaluations of this shipping lane are presented in Table 5.8. In addition, the original evaluation of the company is also presented.

Table 5.8: Carrier performance- Shipping lane A

Carrier	Performance Score	Evaluation	Company Evaluation
A1	0.429	3	2
B1	0.362	5	5
C1	0.391	4	3
D1	0.545	2	1
E1	0.266	6	6
F1	0.622	1	4

From the results in Table 5.8, it can be seen that carrier E1 has the lowest performance score, being evaluated last in both evaluations. This shows consensus on the position of this carrier as the least favourable option among all available carriers. Carriers B1 and C1 have performance scores very close to each other, with both evaluations placing B1 5th and C1 in the middle, indicating a consistent view of their relative performance.

Carrier A1, evaluated third in the tool, is evaluated second by the company, suggesting a higher preference potentially influenced by *Price*, as this carrier has a lower price compared to others. F1, with the highest score in the tool, indicates it is closest to the ideal solution, but the company evaluates it fourth, indicating that they might be considering factors not covered by the tool.

The differences in the evaluations of the top carriers, particularly the discrepancy in which carrier is evaluated number one, can be attributed to the evaluation criteria used. The company's approach of lexicographic ordering, as detailed in subsection 4.8.1, leads to prioritisation of *Price*. D1, having the lowest *Price*, is evaluated highest by the company. This priority influences evaluations of the other carriers too, with the second-evaluated carrier also favoured for better pricing compared to others. In contrast, the tool evaluates F1 highest because of its superior performance on criteria considered after *Price*, while its second-evaluated carrier, though scoring well on *Price*, performs more averagely on other criteria.

Table 5.9: Costs difference - Shipping lane A

	80 TEU		20 TEU		
Evaluation	Carrier	Costs	Carrier	Costs	Total costs
Company	D1	$84,000	A1	$26,580	$110,580
Tool	F1	$125,200	D1	$21,000	$146,200
Difference in costs 100 TEU					$35,620
Difference in costs 1 TEU					$356.20

When looking at Table 5.9, the difference in costs between the company's evaluation and the tool's evaluation is significant. The additional costs amount to nearly a quarter of the original price. Consequently, the tool's outcome is considerably more expensive than the company's initial evaluation. This indicates that incorporating sustainability in this scenario entails a substantial additional cost.

From this shipping lane, it can be concluded that the company follows lexicographic ordering. Furthermore, the tool thus includes scores on other criteria in the evaluation and these do have an effect despite a relatively large difference in scores on the most important criterion for the company. Therefore, strong performance on social and environmental criteria does have an impact. Moreover, when comparing costs, the tool results in a more expensive option, indicating that incorporating sustainability in this case is costly.

5.5.2. TOPSIS - Shipping lane B

From the performance matrix in Table 5.4, a normalised performance matrix is created, presented in Table 5.10.

Table 5.10: Normalised performance matrix - Shipping lane B

	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}	w_{11}	w_{12}	w_{13}	w_{14}	w_{15}
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
A2	0.44	0.16	0.52	0.41	0.29	0.14	0.14	0.20	0.31	0.40	0.44	0.48	0.47	0.45	0.41
B2	0.33	0.32	0.36	0.41	0.20	0.28	0.34	0.00	0.48	0.42	0.39	0.39	0.38	0.52	0.41
C2	0.33	0.16	0.40	0.41	0.22	0.21	0.26	0.90	0.40	0.41	0.41	0.39	0.37	0.18	0.41
D2	0.44	0.16	0.40	0.41	0.58	0.28	0.42	0.40	0.40	0.36	0.36	0.32	0.31	0.20	0.41
E2	0.44	0.64	0.38	0.41	0.55	0.84	0.14	0.00	0.16	0.45	0.44	0.20	0.55	0.30	0.41
F2	0.44	0.64	0.36	0.41	0.43	0.28	0.77	0.00	0.57	0.40	0.41	0.57	0.31	0.61	0.41

Following the normalised performance matrix, the weighted normalised performance matrix is created and reflected in Table 5.11. Hereafter, the ideal best and ideal worst carriers on each criterion are determined. Then the Euclidean distances are calculated and finally, the performance scores are calculated from which an evaluation follows. An overview of the performance scores and evaluations is shown in Table 5.12.

Table 5.11: Weighted Normalised Performance Matrix - Shipping lane B

	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}	w_{11}	w_{12}	w_{13}	w_{14}	w_{15}
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
A2	0.042	0.013	0.056	0.040	0.048	0.016	0.011	0.005	0.007	0.009	0.010	0.022	0.018	0.014	0.021
B2	0.032	0.027	0.039	0.040	0.033	0.032	0.025	0.000	0.011	0.010	0.009	0.018	0.014	0.016	0.021
C2	0.032	0.013	0.043	0.040	0.036	0.024	0.019	0.021	0.009	0.010	0.009	0.018	0.014	0.005	0.021
D2	0.042	0.013	0.043	0.040	0.097	0.032	0.031	0.009	0.009	0.008	0.008	0.015	0.012	0.006	0.021
E2	0.042	0.053	0.041	0.040	0.091	0.097	0.011	0.000	0.004	0.010	0.010	0.009	0.021	0.009	0.021
F2	0.042	0.053	0.039	0.040	0.072	0.032	0.057	0.000	0.013	0.009	0.009	0.026	0.012	0.019	0.021

Table 5.12: Carrier performance - Shipping lane B

Carrier	Performance Score	Evaluation	Company Evaluation
A2	0.584	4	3
B2	0.671	1	1
C2	0.616	3	2
D2	0.464	5	5
E2	0.326	6	6
F2	0.656	2	4

From the data in Table 5.12, it is evident that carrier E2, which is evaluated last (sixth), has a significantly lower performance score compared to the next carrier, D2. D2 also has a notable gap from the fourth-evaluated A2. These large gaps are apparent among the lower-evaluated carriers. However, the differences between the top four carriers (B2, F2, C2, A2) are very small. It is unusual for the two largest carriers in this study to be so close to each other, such proximity is not observed for the other two shipping lanes.

Both the tool and the company evaluations agree on the evaluations for the carriers placed first, fifth, and sixth, but they differ for the other positions. Notably, the tool's second-best, F2, is evaluated fourth by the company. This difference is probably because the company uses lexicographic ordering, prioritising *Price* more than other criteria. Carrier B2 is evaluated as the top carrier by the company due to its best score on *Price*. Carrier C2, having the next lowest price score, is evaluated second by the company.

However, the tool considers a wider range of criteria. While it agrees with the company on the top spot for B2, it evaluates F2 as second probably due to its strong performance across other important criteria. These additional criteria, which are valued by the tool, push F2's ranking up in the tool's evaluation compared to the company's. This shows how using different criteria for evaluation can lead to variations in evaluations.

Table 5.13: Costs difference - Shipping lane B

	80 TEU		20 TEU		
Evaluation	Carrier	Costs	Carrier	Costs	Total costs
Company	B2	$29,440	C2	$7,340	$36,780
Tool	B2	$29,440	F2	$13,800	$43,240
Difference in costs 100 TEU					$6,460
Difference in costs 1 TEU					$64.6

As can be seen in Table 5.13, following the tool's evaluation for this shipping lane does cost more money. However, the additional costs are not as large as for shipping lane A. The additional costs for this shipping lane are just under a fifth of the original total price. Therefore, choosing to incorporate sustainability objectives results in this case in a smaller extra expense.

The evaluation of this shipping lane reveals slight differences between the tool's evaluation and the company's evaluation. This suggests that the tool's comprehensive consideration of all criteria scores may lead to subtle variations. Furthermore, the company's use of lexicographic ordering is evident, with the main criterion being *Price* leading the evaluation. Importantly, the analysis shows that adopting the tool's evaluation and thus opting for a more sustainable approach again results in additional costs, even if they are lower than for shipping lane A.

5.5.3. TOPSIS - Shipping lane C

From the performance matrix in Table 5.5, a normalised performance matrix is created, presented in Table 5.14.

Table 5.14: Normalised performance matrix - Shipping lane C

	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}	w_{11}	w_{12}	w_{13}	w_{14}	w_{15}
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
A3	0.52	0.21	0.52	0.5	0.56	0.13	0.25	0.45	0.43	0.49	0.54	0.52	0.54	0.58	0.56
B3	0.26	0.43	0.38	0.5	0.42	0.26	0.59	0.00	0.68	0.51	0.47	0.50	0.43	0.67	0.37
C3	0.77	0.21	0.68	0.5	0.59	0.53	0.73	0.89	0.56	0.44	0.44	0.44	0.36	0.26	0.37
D3	0.26	0.85	0.35	0.5	0.41	0.79	0.25	0.00	0.22	0.55	0.54	0.54	0.63	0.39	0.65

From the normalised performance matrix, the weighted normalised performance matrix is created and presented in Table 5.15.

Table 5.15: Weighted Normalised Performance Matrix - Shipping lane C

	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}	w_{11}	w_{12}	w_{13}	w_{14}	w_{15}
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
A3	0.050	0.018	0.055	0.049	0.092	0.015	0.018	0.010	0.010	0.012	0.013	0.023	0.021	0.018	0.029
B3	0.025	0.036	0.041	0.049	0.069	0.031	0.044	0.000	0.016	0.012	0.011	0.023	0.017	0.021	0.019
C3	0.074	0.018	0.073	0.049	0.097	0.061	0.054	0.021	0.013	0.010	0.010	0.020	0.014	0.008	0.019
D3	0.025	0.071	0.038	0.049	0.068	0.092	0.018	0.000	0.005	0.013	0.013	0.025	0.024	0.012	0.033

After the weighted normalised performance matrix, the ideal best and ideal worst carriers on each criterion are determined. Then the Euclidean distances are calculated and finally, the performance scores are calculated from which an evaluation follows. An overview of the performance scores and corresponding evaluation that are obtained are presented in Table 5.16.

Table 5.16: Carrier performance - Shipping lane C

Carrier	Performance Score	Evaluation	Company Evaluation
A3	0.521	2	3
B3	0.689	1	1
C3	0.337	4	4
D3	0.511	3	2

From the results presented in Table 5.16, it is evident that the lowest-evaluated carrier, C3, has a significantly lower performance score compared to the others. The second and third-evaluated carriers, A3 and D3 respectively, have very close performance scores, while the top-evaluated carrier, B3, is clearly performing better.

Interestingly, the company evaluates B3 as the top carrier despite its *Price* being slightly higher than that of D3. The small difference in *Price* leads the company to apply lexicographic ordering, where the next important criterion, the *IMO Surcharge* (C_6), plays a critical role. B3 performs significantly better in this criterion, which justifies its top position in the company's evaluation.

Comparing the tool's evaluation with the company's, there are slight differences. The top and bottom evaluations (B3 and C3) match in both evaluations, but the second and third evaluations are swapped. This variation is anticipated as D3 has a considerably lower *Price* than A3, and since *Price* is the most critical criterion for the company, this influences their evaluation order. The company's use of lexicographic ordering supports this evaluation structure. However, the tool considers all criteria for its evaluation, leading to A3 scoring better on the second most important criterion (C_6) than D3, affecting their evaluations differently in the tool's evaluation. Despite this, the performance scores of A3 and D3 are very close, showing how competitive they are with each other.

Table 5.17: Costs difference - Shipping lane C

	80 TEU		**20 TEU**		
Evaluation	Carrier	Costs	Carrier	Costs	Total costs
Company	B3	$73,440	D3	$22,280	$95,720
Tool	B3	$73,440	A3	$22,820	$96,260
Difference in costs 100 TEU					$540
Difference in costs 1 TEU					$5.4

As shown in Table 5.17, the cost difference is minimal. The additional costs are only 0.56% of the original total costs. According to the tool's evaluation, the cost will be only $5.4 higher per TEU, which is a negligible amount. In this case, following the tool's evaluation and opting for a more sustainable choice is not significantly more expensive and would be a wise decision.

It can be concluded that the tool's consideration of all criteria scores may result in minor differences compared to the company's evaluation. Additionally, it is evident that the company make use of lexicographic ordering, as the evaluation was determined by the second most important criterion due to a small difference in the primary criterion *Price*. Finally, this shipping lane demonstrates that adopting the tool's evaluation, and thus a more sustainable approach, is not necessarily more expensive.

5.5.4. Conclusion TOPSIS evaluations

From the TOPSIS evaluations, it can be concluded that the results of the tool reasonably match the company's results. The differences are mostly small, with one place difference in ranking. Only in two cases, the difference is larger. However, this difference can be explained by the company's use of lexicographic ordering, which prioritises certain criteria like *Price*, leading to different evaluations than the tool's more comprehensive criteria evaluation. For example, carriers that perform very well on secondary criteria might rank higher in the tool's evaluation. Additionally, there are minimal differences in the evaluation of the lowest-scoring carriers across all shipping lanes, indicating a consistent recognition of poor performance between the company and the tool. This consistency suggests a reliable assessment of under-performing carriers.

Company evaluations may be based on past performance data, which may explain why recent poor performance by some carriers does not affect their evaluations leading to different outcomes. This aspect of the company's evaluation methodology highlights the potential influence of *Past Performance* on current evaluations, which might not be immediately apparent in the tool's real-time assessments. Overall, while there are instances where the tool and company evaluations differ, these can be logically explained by differences in prioritisation and data usage, confirming the general robustness of both evaluation methods.

Moreover, following the tool's evaluation entails different additional costs for different shipping lanes. These costs can vary significantly, ranging from \$350 per TEU to \$5 per TEU, and from 25% to 0.56% of the original total costs in additional expenses. While choosing a more sustainable approach can be relatively inexpensive if the additional costs are minimal, it is clear that following the tool in all three cases involves additional costs, even if these costs are minimal. Additionally, compliance with the tool's evaluation was already expected to lead to additional costs, as the tool differs from the company's lexicographic ordering approach, where *Price* is the most important criterion.

Lastly, across all three shipping lanes, no difference is observed in the score for C_4, representing *Confirmed Allocation*. However, it is advisable to maintain this criterion for future use, as carrier variation could influence it. Although identical scores on this criterion do not affect the overall evaluation or introduce variability, they ensure the robustness and effectiveness of the TOPSIS analysis, as demonstrated by the squared difference of zero in Euclidean distance calculations and the equal normalised scores.

5.6. Sensitivity analyses

In this section, various sensitivity analyses are conducted. Sensitivity analyses are performed to see the effect of small changes. Moreover, this helps to explore the impact of the limitations of this study. For these analyses, the weights are adjusted, and therefore, the method for calculating changes in weights is explained first. Secondly, a percentage weight adjustment is conducted. Thirdly, scenario analyses are described and presented. Finally, a conclusion of the analyses is presented.

5.6.1. Calculation of change in weights

Within this section, weights of various criteria and categories are adjusted, affecting the calculation of other weights. The total sum of weights must remain 1 for normalisation, ensuring easy comparison and proportional influence. This approach simplifies calculations, maintains consistency, and enhances transparency and interpretability. The following calculation is applied to achieve this and is explained below.

1. Let w_i be the initial weight of criterion i which weight is going to be changed.
2. Let w_j be the initial weight of any criterion j, and w'_j be the new weight of any criterion j.
3. Let w_{new} be the new weight assigned to one specific criterion.
4. The remaining weight to distribute among the other criteria is $1 - w_{\text{new}}$.

Define:

- S_{orig} as the sum of the original weights of the remaining criteria, i.e., $S_{\text{orig}} = 1 - w_i$

For each remaining criterion $j \neq i$, the new weight w'_j is calculated as follows:

$$w'_j = \left(\frac{w_j}{S_{\text{orig}}}\right) \times (1 - w_{\text{new}}) \tag{5.6}$$

This formula ensures the total sum of all weights remains 1 after adjusting the weight of criterion i.

5.6.2. Percentage weight adjustment

A percentage weight adjustment is conducted to determine the implications of employing varied values for the weights in TOPSIS. It is assumed that the scores that are filled in for the criteria are reliable so therefore no percentage weight adjustment analysis is done for those values. The percentage weight adjustment is done for the three most important shipping lanes that have been used previously during this research. For the percentage weight adjustment, the weight of each criterion is increased by 5% and 10% but also decreased by 5% and 10%. The left weights are calculated as explained in subsection 5.6.1. The results of the percentage weight adjustment per shipping lane are presented in Appendix G.

From the results presented in Appendix G it can be seen that no changes in evaluation occur for the shipping lanes A and B. This is expected as the original performance scores for these shipping lanes do not lay that close to each other. Furthermore, some small changes occur for shipping lane C. For this shipping lane the numbers two and three swap places when changing the weights for the criteria *Rate Validity* and *IMO Surcharge*. These carriers swapping places is as expected, as the performance scores of these carriers in this shipping lane are very close to each other. These carriers differ only 0.009 in performance scores. Furthermore, it is likely that only for these criteria do the carriers swap places because they have very different scores within those criteria as can be seen in Table 5.5.

From this percentage weight adjustment, it can be concluded that when changing the weights of each criterion the order of the carriers does not change significantly. The evaluation remains consistent and is not sensitive to change. This suggests that the chosen criteria and weights are robust and reliable.

5.6.3. Scenario analyses

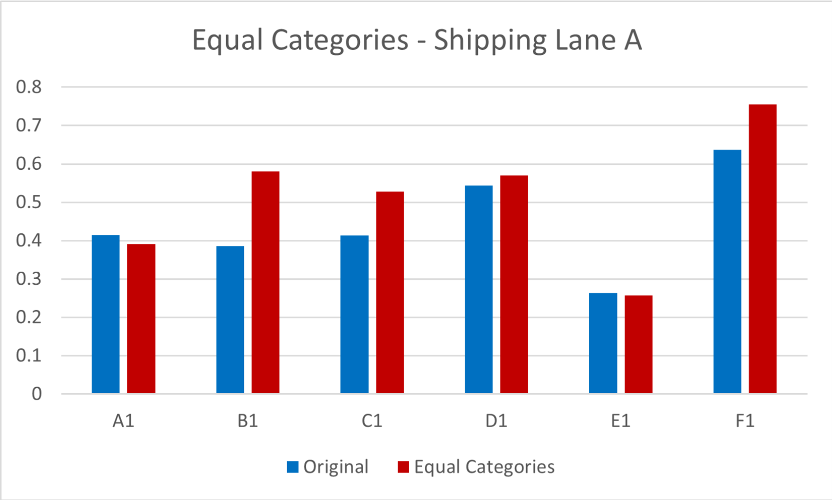
Scenario analyses are conducted to explore different futures and manage uncertainty. By exploring multiple scenarios, strategies become robust and adaptable, leading to more informed decisions and better risk assessment. It also validates tool findings under different conditions, increasing the credibility of the study. Finally, it identifies key factors that significantly impact outcomes and guide strategic focus.

For this study, several scenario analyses are performed. First, scenario analysis is performed by equalising the category weights. After this, a scenario analysis is done by changing the scores of the economic criteria. Finally, a scenario analysis is executed in which some category weights are a little increased or decreased. To calculate the left weights of categories the principle explained in subsection 5.6.1 is applied.

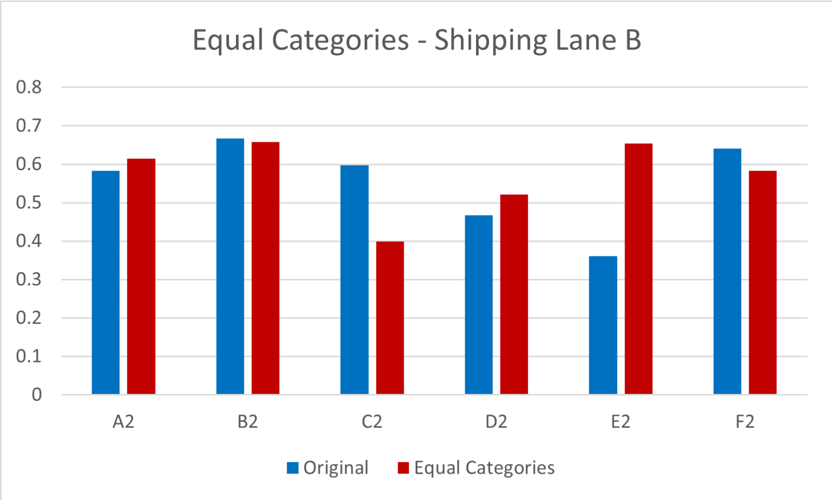
5.6.3.1. Scenario analysis 1 - Equal category weights

First, it is interesting to examine the effect of assigning equal importance to all categories. Historically, policies often prioritised economic growth over social and environmental considerations. This leads to unbalances and unsustainable practices. Recent global trends and increasing awareness of climate change, social inequality, and economic inequality have requested calls for a more integrated approach to sustainability. Therefore, it is likely that the government will introduce a new regulation requiring all sustainability policies and projects to equally consider and weigh the economic, social, and environmental categories. This regulation aims to create a balanced approach to sustainable development that addresses the needs of current and future generations entirely. In this ideal sustainable situation, companies that do not comply with this regulation will not be allowed to continue their business operations. This makes it interesting to look into the effect of this scenario on carrier evaluation.

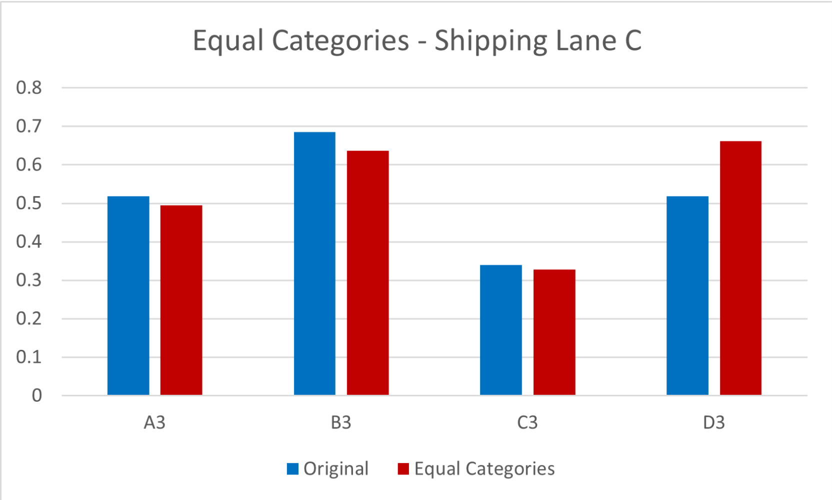
The new weights that follow from this scenario are applied to the three previously used shipping lanes. The results are presented in Figure 5.4.



(a) Equal categories - Shipping lane A



(b) Equal categories - Shipping lane B



(c) Equal categories - Shipping lane C

Figure 5.4: Equal categories - Shipping lanes

By looking at Figure 5.4, changes in all shipping lanes are evident. The original outcome (blue) should be compared with the new outcome where each category contributes equally (red). It is expected that the social and environmental categories will now have a larger impact, benefiting carriers that score well in these categories.

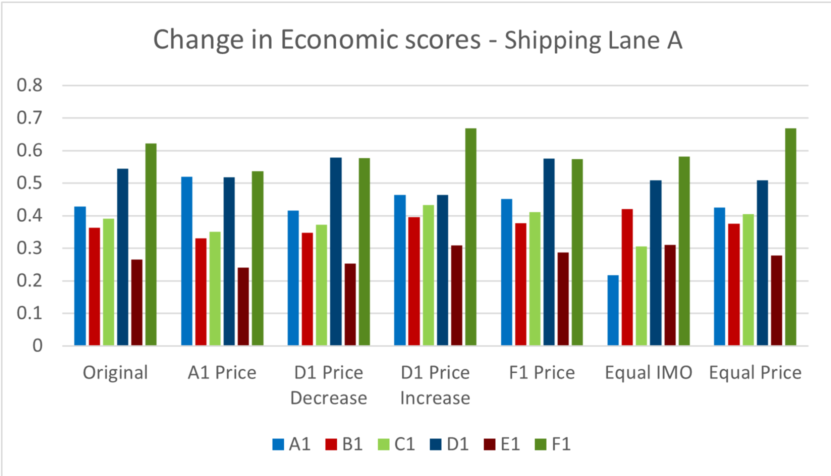
In Figure 5.4a, it can be seen that carrier B1 performs much better, likely due to its strong social and environmental scores, as shown in Table 5.3. Although carrier A1 scores high on economic criteria, its poorer social and environmental performance causes it to do worse overall. Carriers E1 and F1 maintain their positions, while the performance differences among carriers B1, C1, and D1 have become closer compared to A1, B1 and C1 previously. In Figure 5.4b, most carriers change positions except for B2 and D2. Carrier C2 drops three places while carrier E2 climbs four places due to excellent social and environmental scores, as indicated in Table 5.4. Carrier F2 also drops because of its weaker social and environmental performance and average economic scores. Figure 5.4c shows that carrier C3 remains in place due to its poor scores, while carrier D3 improves significantly probably due to its strong social and environmental performance. Carriers A3 and B3 drop one place each, likely due to their average scores in social and environmental criteria despite doing well economically.

This scenario analysis shows the significant impact of giving equal weight to economic, social, and environmental criteria. Carriers that previously relied on economic strength see their rankings drop, while those with strong social and environmental performance improve. With equal weighting, social and environmental criteria contribute more, boosting carriers that excel in these categories. Although economic criteria still matter, a high evaluation requires strong performance in all categories. This balanced approach highlights the importance of considering social and environmental impacts, leading to more comprehensive and fair decision-making.

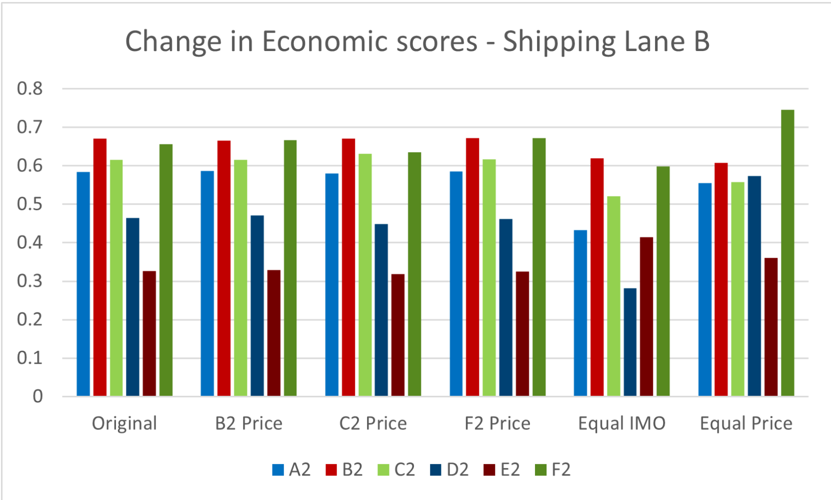
5.6.3.2. Scenario analysis 2 - Change in economic scores

As mentioned earlier, the global shipping industry is crucial for international trade but it faces significant challenges. Partly due to unpredictable economic factors. While economic criteria are likely to change quickly due to politics and wars, social and environmental criteria are expected to remain relatively stable, as they are primarily based on the sustainability reports of the carriers, which are updated annually. Historically, the industry has experienced fluctuations driven by geopolitical events, economic sanctions, and natural disasters. For instance, the oil crises of the 1970s, driven by geopolitical tensions in the Middle East, caused fuel prices to increase enormously. This significantly impacted shipping costs and operations. More recently, conflicts between countries have introduced new uncertainties in economic criteria. For example, prices increased enormously due to issues in the Red Sea region, which also caused transit-times to become longer. Real events such as a conflict disrupting oil supplies, sanctions against a major oil-producing country, or a hurricane affecting oil production could increase fuel prices. Carriers then have to adjust routes, find alternative fuel sources, renegotiate contracts, or invest in more fuel-efficient technologies to meet these challenges effectively. This further demonstrates the volatile nature of the economic environment in which the industry operates.

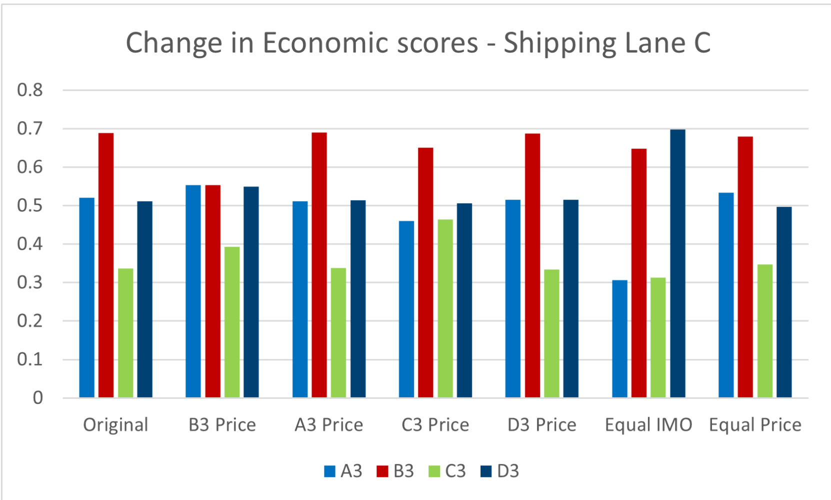
This scenario analysis therefore examines how quick changes in economic scores impact carrier evaluation, focusing on the fast-changing global environment. Imagine an overnight blockade of a crucial shipping route due to a geopolitical conflict. This would lead to a sudden and significant increase in fuel prices. Such an event can occur unexpectedly and have a substantial impact on carrier evaluations due to the weighting of economic criteria, making it an interesting development to watch. Furthermore, it is also possible that a decision could be made by the authorities to standardise *IMO Surcharge* for all carriers, preventing them from setting these costs independently. When one of those two scenarios happens, carriers must quickly adjust to these changes, which can affect their competitiveness and profitability. This analysis helps to understand how well carriers can adapt to economic volatility and its impact. Moreover, it also gives insight into what effect such an event has on carrier evaluation.



(a) Change in economic scores - Shipping lane A



(b) Change in economic scores - Shipping lane B



(c) Change in economic scores - Shipping lane C

Figure 5.5: Change in economic scores - Shipping lanes

Figure 5.5a shows that changes in the criterion *Price* significantly impact carrier evaluation. The original top carrier, F1, drops one place when its price increases from $1490 to $1860, and D1 becomes number one when its price drops from $925 to $640. When D1's price increases from $925 to $2000, it drops one place, making most carriers closely evaluated. A1's price drop from $1233 to $420 brings A1, D1, and F1 closer in evaluation. Uniform scores for the criterion *IMO Surcharge* cause carriers with previously low charges to drop in ranking, while those with high charges improve. Except for carrier F1, this carrier remains in place with a lower *IMO Surcharge* ($75). When all values for the criterion *Price* are the same, no changes in evaluation occur. The gap between the evaluated numbers one and two becomes even larger.

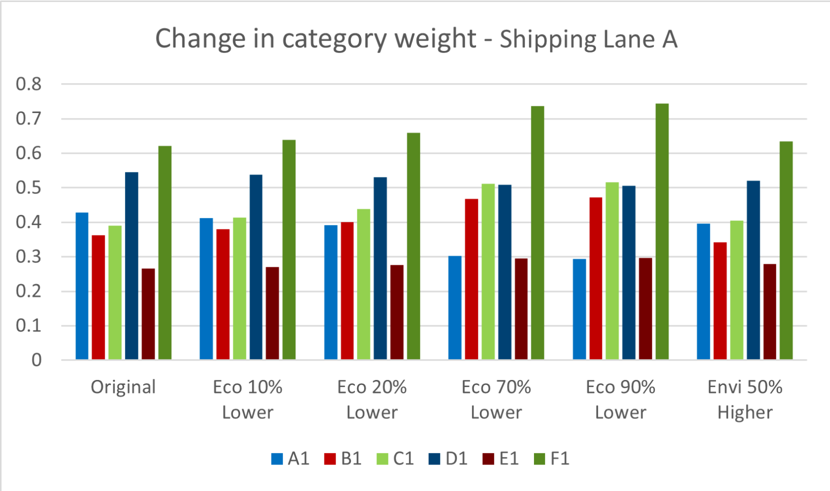
Figure 5.5b shows that evaluations are sensitive to relatively small changes in the criterion *Price* as some original performance scores are close. B2 drops to second place if its price increases from $268 to $300, and C2 climbs one place if it drops the price from $292 to $220. F2 becomes first if its price drops from $590 to $555. Equalising the value for the criterion *Price* causes many shifts, each carrier changes place except for carrier E2. The carriers A2, B2, C2 and D2 become very close to each other, while carrier F2 stands out as the number one. This evens out advantages or disadvantages previously caused by the price differences. Additionally, uniform *IMO Surcharge* maintains consistency in evaluations, except for carriers D2 and E2 swapping places. E2 notably improves, likely due to its high initial value for *IMO Surcharge*.

Lastly, Figure 5.5c shows that B3 drops one place if its price increases from $801 to$1690, making A3, B3, and D3 closely ranked. A3 drops one place with a $100 increase, and C3 climbs one place if its price drops from $1123 to $490. D3 rises one place with a $50 drop. Uniform values for the criterion *IMO Surcharge* make D3 the top carrier, with B3 closely following, and A3 and C3 close in evaluation. Uniform values for the criterion *Price* cause no major evaluation changes.

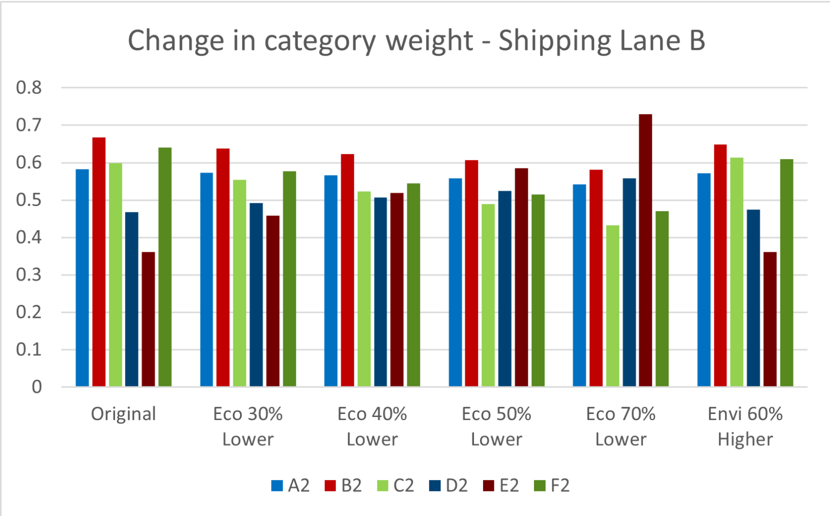
This scenario analysis shows that economic criteria particularly changes in the criterion *Price*, significantly influence evaluations. Although the sensitivity varies. Large price changes can cause small shifts in evaluation, while small price changes can lead to significant reordering, especially when carriers originally have a performance score very close to each other. When the values for the criteria *IMO Surcharge* and *Price* are the same for all carriers, other criteria become more important in determining evaluation. Therefore, carriers need to carefully manage their prices and be aware of economic changes to stay competitive, as even small adjustments can have a big impact.

5.6.3.3. Scenario analysis 3 - Little increase or decrease in category weight

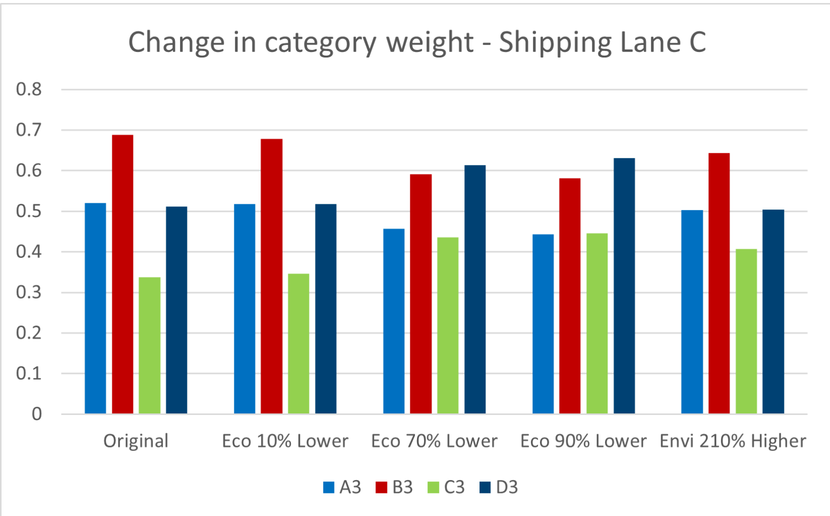
In this scenario, the impact of small changes in the weighting of categories on carrier evaluation is explored. Specifically, it examines how reducing the importance of the economic category and increasing the weight of the environmental category affects carrier evaluation. This incremental approach is interesting because companies often prefer gradual changes over major overhauls. It is useful to understand how much adjustment is needed to see a significant impact. The social category remains constant as all carriers are expected to meet basic social responsibility standards. Suppose the government comes up with new regulations to make maritime transport more sustainable. As a result of these new regulations, the government gives shipping companies five years to switch to them. The government is doing this so that companies can remain operational and think carefully about a sustainable implementation. Thus, shipping companies will not have to switch overnight, but gradually over five years. This gradual shift is designed to encourage sustainable practices without disrupting operations. During this period, shipping companies gradually reduce the weighting of the economic category and increase the weighting of the environmental category by the same amount.



(a) Change in category weights - Shipping lane A



(b) Change in category weights - Shipping lane B



(c) Change in category weights - Shipping lane C

Figure 5.6: Change in category weights - Shipping lanes

In Figure 5.6a, a 10% decrease in the economic category weight causes carriers A1 and C1 to swap places, with A1 dropping one place. When the economic category weight is dropped to 20% carrier B1, climbs up one place and carrier A1 drops one more place, due to its weaker social and environmental scores. This shift remains until the economic weight is decreased by 70%. Then Carriers C1 and D1 swap places. When the weight is dropped to 90% only carrier F1 maintains its position at the top. Carrier A1 ends up in the last position instead of carrier E1. Similarly, a 50% increase in the environmental weight swaps A1 and C1, probably due to the better social and environmental performance of carrier C1. No further changes occur even with a doubled environmental weight.

Figure 5.6b, shows a 30% decrease in economic weight swaps A2 and C2, reflecting A2's stronger social and environmental performance, but also due to their close original score. A 40% decrease significantly changes evaluations except for B2, bringing performance scores closer. E2 rises to the top with a 50% economic reduction. E2 even reaches the top position and maintains this position from 60% economic reductions and onward. Furthermore, from a 70% decrease, the differences between the carriers become larger. Probably due to their very different performance in all the social and environmental criteria. Increasing the environmental weight by 60% causes carriers C2 and F2 to swap places which remains even when environmental is made twice as important as originally.

In Figure 5.6c, a 10% decrease in economic weight swaps A3 and D3, with D3 excelling in social and environmental scores. This change holds until a 70% reduction of the economic weight, after which D3 takes the top spot. When economic weight is decreased by 90% the gap between carriers B3 and D3 becomes larger and carriers A3 and C3 swap places as C3 performs better on social and environmental criteria. Only when the environmental weight is increased by 210%, carriers A3 and D3 change places. However, carrier D3 overall clearly performs much better on the social and environmental criteria than carrier A3.

This scenario analysis shows that the carrier's evaluation is strongly influenced by changes in the weightings of the economic category. For instance, shifts already occur when the weighting of the economic category is reduced by a small percentage. In contrast, increasing the weighting of the environmental category leads to fewer shifts. Only when this category is increased by a large percentage, does a shift occur, which continues hereafter but does not lead to multiple shifts. So reducing the weight of the economic category has more impact than increasing the environmental category, which was also to be expected since the economic category in its original status also has the most impact. Furthermore, carriers with balanced scores remain stable, while those with significant differences are more affected. Initial changes are seen for carriers with similar performance scores. Moreover, once a change occurs, it often persists. When the economic or environmental category changes in the level of importance, some carriers' scores may converge. This underscores the potential of adjustments to evaluation criteria that can impact strategic priorities and sustainability goals.

5.6.4. Conclusion sensitivity analyses

Overall, the percentage weight adjustment confirms the robustness and stability of the weights and the tool, ensuring the reliability of the subsequent scenario analysis. The scenario analyses reveal significant shifts in carrier evaluations when weights are adjusted, with equal weighting notably benefiting carriers with strong social and environmental performance. This analysis highlights the importance of balanced performance across categories, the impact of standardised *IMO Surcharge* and *Price* scores, and economic weight adjustments.

5.7. Verification and validation

The tool and the decision-making process in which the tool is used are verified by the constraints and objectives presented in section 3.2. The constraints must be met and the objectives preferably to a great extent. Below is described if and how the (non-) functional constraints and objectives are met in both cases.

5.7.1. Tool verification

5.7.1.1. Constraints tool

From the results presented above it can be concluded that FC1, FC2, FC3 and FC4 are met. The tool operates within seconds, satisfying FC5. Additionally, FC6 is fulfilled as the original criteria identified by the company (*Service*, *Transit-time*, *Confirmed Allocation*, and *Price*) are included in the tool. NFC1 and NFC2 are met because the tool is made in Excel, which the company already uses. The scenario analysis confirms that NFC4 is met, and NFC5 is also satisfied as no investment costs are required. Lastly, the clear overview of the tool makes it understandable for carriers, meeting NFC3.

5.7.1.2. Objectives tool

FO1 is met as different stakeholders are interviewed and taken into account during the research. FO3 is also met as it takes seconds. In addition, FO2 and FO4 are largely fulfilled. Although running the tool currently involves several steps, it can be easily automated with future improvements. The tool operates on accurate data, but the social and environmental criteria scores may be somewhat outdated and could be updated. Additionally, NFO1, NFO2, and NFO3 are met. For NFO4, the tool runs on input data where comments are ignored: future work should ensure that the input data does not include a space for comments.

5.7.2. Decision-making process verification

5.7.2.1. Constraints decision-making process

The decision-making is following regulations, and meeting FC1. Furthermore, FC2 is satisfied as economic, social, and environmental criteria are included in the tool. FC3 is achieved because the tool has become integral to the decision-making process. Additionally, FC4 is met as the tool provides an evaluation on which a decision can be based. FC5 is fulfilled since results can be evaluated and adjusted before making a decision. Within the decision-making process, no secret steps are taken, to meet NFC1. The decision is based on accurate data, satisfying NFC2. The process follows a clear structure, making it understandable to the carriers and meeting NFC3. The results demonstrate that it is repeatable across multiple shipping lanes, thus meeting NFC4.

5.7.2.2. Objectives decision-making process

FO1 is met to a great extent, and with future adjustments and automation, it will become even more efficient. FO2 is almost met, as company stakeholders are largely satisfied, though they still place significant importance on economic criteria. FO3 aligns well with organisational goals by incorporating multiple criteria and steps to mitigate risks, although not all risks are entirely mitigated, thus meeting FO4 to a great extent. Additionally, the tool is well-structured, fulfilling NFO1, and it requires minimal financial investment, satisfying NFO2. Finally, since carriers gain insight into the decision-making process and the basis for decisions, low resistance is expected, meeting NFO3.

From the above, it can be concluded that all constraints are met and all objectives are met to a great extent. This indicates that the specified requirements are fulfilled. The tool and the decision-making process function as intended.

5.7.3. Validation

Validation is done by asking for feedback from experts in the company during several stages of the research. Besides, the weights determined using BWM are validated by checking the consistency ratio of all BWMs. As mentioned in subsubsection 5.2.1.1, the pairwise comparisons are adjusted if the consistency ratio is not satisfactory. In addition, the sensitivity analysis validates the robustness and reliability of the weights and the tool. The results presented in this chapter have also been validated by discussing them with the experts. This feedback from the experts is used to determine whether the results are useful and could provide an answer to the objective of the research. However, it is important to acknowledge the limitations of this validation approach. The experts have actively participated in the process of determining weights and collecting data. Consequently, their feedback reflects their own contributions, which could potentially bias their feedback due to their prior involvement.

It is expected that the experts have something of a commentary on the results, as it is already clear from the results that the tool's evaluation is different from the company's evaluation. It is anticipated that the experts will mainly look at the price and evaluate the differences on this basis.

The discussion with the experts reveals that they find the results convincing, especially since there is not much variance, and the carriers preferred by the company score highly. However, during discussions, it becomes apparent that operational familiarity plays a significant role in the company's carrier preference. If the company is used to working with a particular carrier, it may prioritise stability over cost savings, even if another carrier offers a slightly lower price. This is because switching carriers involves risks, and the company may be willing to pay a little more to minimise these risks. In addition, experts note that they usually look at the total cost, i.e. the criteria *Price*, *IMO Surcharge* and *ETS Fee* added together. They do this especially when a carrier offers a significantly lower price.

Despite the convincing results, experts express the need for future research on the inclusion of operational familiarity before using the tool directly. However, it is acknowledged that the *Past Performance* criterion may indirectly account for this. Furthermore, the company states that they find it challenging to rely on a carrier's environmental scores, as it is difficult for them to independently verify these scores. Consequently, they must depend on the provided scores, despite having no alternative. In summary, while the results are validated and accurate, they do not perfectly align with the company's internal evaluations. Nonetheless, the tool meets many user needs and expectations, although further research could be done to effectively integrate operational familiarity into the evaluation.

5.7.4. Conclusion verification and validation

The verification process validates the tool and decision-making process by confirming that all constraints are met and objectives largely achieved. Expert feedback and consistency ratio checks validate the tool's effectiveness, though future research should integrate operational familiarity considerations to enhance alignment with company evaluations. Thus, the study promotes a more comprehensive and sustainable approach to carrier evaluation.

5.8. Advantages compared to current carrier selection

From the results presented above it becomes clear that using the tool for carrier selection has several advantages compared to how carriers are currently selected. The advantages of the tool are listed below.

- **Considers sustainability criteria.** This ensures that it can be used in the future and that more sustainable carriers can be gradually moved towards.
- **Structured and consistent decision-making.** This ensures that the different regions of the company select their carriers based on the same criteria. This creates a common approach that is easy to follow.
- **Carrier evaluation based on multiple criteria, minimising risks.** In the past, the carrier evaluation was solely based on *Price*, which is subject to significant fluctuations. The tool now prioritises multiple criteria, thereby mitigating risks and avoiding reliance solely on one criterion.
- **Easy to interpret.** The input required by the tool and its final assessment is simple and concise. It consists only of quantitative data, making it quick to understand.
- **Saves time.** This way of selecting carriers saves time. First, an evaluation is done automatically based on the data to be loaded. In addition, it also becomes clear to carriers how they are evaluated, which also makes it faster and easier for them to adjust their scores because they know how they are assessed.
- **Less information and data needed.** In theory, less information is needed than before. In principle, carriers only have to provide data for the various criteria and nothing else, because an evaluation is made based on these criteria.
- **First step to more automatic and data generated decisions.** Automation and digitisation are expected to increase in the future and this decision-making method can contribute to this. Initially, human input is needed to check the criteria and their weighting, but then the process can be automated using tools such as a Python model to automatically generate outcomes.

- **Can be used to negotiate.** This benefit is seen as one of the biggest advantages and will therefore be explained in more detail below.

Negotiating can be seen as the biggest advantage of the tool. There are five points within negotiating to which it can contribute. These points are listed and discussed below.

1. **Well-informed negotiating.** First of all, the company will enter the negotiations with a clear overview of the strengths and weaknesses of each carrier. This information enables the company to conduct discussions with carriers that are more informed and targeted.
2. **Determine negotiating points.** The tool identifies carrier strengths and weaknesses. For instance, if carrier A offers superior reliability but higher prices than carrier B, the company can leverage this information to negotiate better pricing with carrier A or adjust other terms, like service agreements, to balance the costs.
3. **Competition use.** By presenting carriers with their rankings in comparison to competitors, the company can create a competitive environment. This motivates carriers to offer more competitive pricing or improved terms to win the business.
4. **Negotiating terms and conditions.** The tool will also allow the company to negotiate on criteria like *Transit-time*, *Confirmed Allocation*, CO_2 *Emission per Shipment*, and *Service*. Using the evaluations, the company can justify their negotiation positions and ensure the selected carrier meets all requirements.
5. **Establishing long-term relationships.** Negotiating is not just about securing a good deal for a single shipment. It is also about building strong, lasting relationships with carriers. The tool helps to find carriers that match the company's values and goals, making it easier to create partnerships that benefit everyone.

5.9. Conclusion results

This chapter presents the findings of the comprehensive approach for evaluating and selecting carriers for transporting tank containers overseas. Initially, 34 criteria are identified through a literature review and interviews, which are then narrowed down to 15 essential criteria grouped into economic, social, and environmental categories. This selection is refined through stakeholder surveys. The MCDM approach, integrating the Best-Worst Method (BWM) and the Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS), forms a robust tool for evaluating carriers. BWM is utilised to determine the weights of the 15 criteria, involving pairwise comparisons within each category to ensure balanced importance. These weights are aggregated to form a single weight for each criterion. Carriers for three specific shipping lanes are then sourced and evaluated using TOPSIS. This involves creating performance matrices based on sourced data and applying the weighted criteria to determine carrier rankings.

The results demonstrate that the tool provides a balanced consideration of economic, social, and environmental criteria, facilitating informed and strategic carrier selection decisions. The sensitivity analyses confirm the stability and reliability of the tool, showing minimal impact from variations in weights. Verification and validation processes ensure the tool meets all specified constraints and objectives, making it effective for decision-making. This structured and systematic approach promotes sustainable practices, provides clear and consistent evaluations, and improves effectiveness. The biggest advantage is its ability to facilitate informed negotiations. By utilising these insights, the company can ensure more transparent, balanced, well-informed, and strategic carrier selection decisions.

6 Conclusion and Discussion

With the findings and results discussed in previous chapters, this research can be concluded. This chapter first provides answers to the research questions. Hereafter, the discussion is presented including limitations, implications and recommendations.

6.1. Conclusion

This research aims to identify and select the best carriers for transporting tank containers overseas by using Multi-Criteria Decision-Making (MCDM), specifically the Best-Worst Method (BWM) and the Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS) with a focus on incorporating sustainability objectives. A case study approach is employed to systematically analyse carrier selection and understand the processes in logistics. The objective is to improve the carrier selection process of the case company, Hoyer, by developing a robust, transparent, and practical method that integrates the three categories of sustainability: economic, social, and environmental. This research tries to reach this goal, by answering the following main research question:

How is a carrier for transporting tank containers overseas selected considering the inclusion of sustainability objectives?

To answer this main research question several sub-questions are developed. In the following paragraphs, these sub-questions will be answered first to eventually develop an answer to the main research question.

How is the process of carrier selection currently executed?

To understand the case company, its current carrier selection process, and the challenges it faces, interviews and secondary data analysis are conducted. The outcomes show that multiple stakeholders are involved in the carrier selection process, with three individual decision-makers playing crucial roles and being equally important. Carriers are selected through a centrally managed tender process in Rotterdam, with input from other Hoyer regions. The process starts by identifying tender requirements and shaping preferences. Currently, carriers are evaluated primarily on *Service*, *Transit-time*, *Confirmed Allocation*, and *Price*, without assigning specific weights to these criteria and with insufficient consideration of environmental and social impacts. After initial bids, Hoyer provides a counter-offer for improvements. Hereafter, two to three carriers are selected for major shipping lanes and one for minor shipping lanes, with the main carrier usually handling 80% of the volume and the secondary carrier 20% to mitigate risks. Regular performance reviews are conducted during the contract period. The interviews indicate that Hoyer implicitly uses lexicographic ordering, with *Price* being the most important criterion. Additionally, the current process lacks a structured approach to include sustainability criteria, which is becoming increasingly important in logistics.

What are essential requirements in the carrier selection process?

The interviews, literature review, and secondary data analysis reveal the key requirements for carrier selection. These requirements are used both as input for the decision-making process and to verify this process and the tool for selecting carriers. The decision-making process involves collecting inputs and making a decision, while the tool evaluates all inputs to facilitate this final decision. A conceptual design has been developed using a flowchart, outlining the crucial steps of this research and distinguishing between the tool and the decision-making process. The key steps in the conceptual design are: identifying criteria considering these requirements, applying BWM to weight these criteria, sourcing carriers in parallel with their scores on the criteria, and consolidating all input into a performance matrix. Based on this matrix, carriers are evaluated and ranked using TOPSIS. A reflection moment is added to reassess criteria based on situational factors, enhancing decision reliability.

To verify the process and tool, requirements are separated into constraints (mandatory requirements) and objectives (desired features) for both the tool and the overall decision-making process. Key requirements include reliability, which includes timely delivery and consistency of service. In addition, cost efficiency evaluates overall cost implications rather than just the initial price. Furthermore, regulatory compliance ensures that carriers adhere to legal and industry standards. Finally, sustainability goals emphasise the importance of reducing environmental impact and promoting social responsibility. These requirements provide a comprehensive and effective carrier selection process.

What sustainability criteria from both literature and internal experts should be considered for carrier selection?

The literature review shows that including sustainability criteria is essential, encompassing economic, social, and environmental criteria. A broad literature review, secondary data analysis and interviews with internal experts generate a long list of criteria, which is reduced to 34 by removing redundancies. A survey with the three key decision-makers further refined this to 15 criteria, divided into economic (seven criteria), social (four criteria), and environmental (four criteria). Economic criteria remain crucial but are now evaluated alongside social and environmental criteria to ensure carriers are cost-effective and contribute positively to social and environmental outcomes. The social category covers fair labour practices and safety standards, while the environmental category focuses on reducing carbon footprint and emissions. These criteria align with Hoyer's strategic goals and industry trends towards sustainable logistics. By integrating feedback from literature and internal experts, the carrier selection process now includes a balanced consideration of economic, social, and environmental criteria, supporting a comprehensive approach to sustainability.

How to find the relative importance (weights) of the criteria?

The Best-Worst Method (BWM) is used to determine the relative importance of criteria. Due to the number of criteria, four analyses with two sets of pairwise comparisons per respondent are performed by Hoyer's decision-makers, deriving weights reflecting their priorities. The analysis shows a consensus: economic criteria are most important, followed by environmental, and then social, given high existing standards. All decision-makers equally value social criteria, but one highlights the criterion *ETS Fee* as more important among environmental criteria. *Price* is the top economic criterion for all, but they differ on *Past Performance*, *Rate Validity*, and *Transit-time*. The weights are aggregated with the use of the geometric mean method to produce a single weight for each category and each criterion. Critical economic criteria are *Price*, *IMO Surcharge*, and *Transit-time*. Significant social criteria are *Work Safety*, *Labour Health*, and *Ethical Issues and Legal Compliance*. Key environmental criteria are CO_2 *Emission per Shipment* and *ETS Fee*. BWM shows that while economic criteria remain crucial, environmental and social criteria also carry significant weight, reflecting Hoyer's commitment to sustainability. This method ensures a systematic and consistent approach to weighting, providing a comprehensive evaluation framework aligning with business and sustainability goals.

How to find the best carrier for transporting tank containers overseas?

In parallel with BWM, carriers are sourced that offer a service on the shipping lanes that are chosen to be evaluated. In this research, three shipping lanes (A, B, and C) are chosen to evaluate due to time constraints and their historical importance. The carriers operating on these lanes are known, allowing their scores on each criterion to be sourced. To objectively evaluate carriers, some criteria require quantification to ensure they adhere to an interval or ratio scale. This is done using sources like sustainability reports, and the preferred direction for each criterion is identified for use in TOPSIS. A performance matrix is established based on the criteria, their weights, and the carriers with their scores. Following the performance matrix, TOPSIS is applied to evaluate the carriers on the three key shipping lanes. The method ensures balanced decision-making by assessing carriers' proximity to the ideal solution and considering trade-offs between criteria. The TOPSIS provides a detailed assessment, ensuring that selected carriers meet the comprehensive set of criteria.

The TOPSIS results show that carriers performing well on multiple criteria rank higher. This approach highlights the benefits of integrating sustainability criteria. Carriers excelling in environmental and social criteria are better evaluated. The outcomes of the tool closely match the company's evaluations, with most differences limited to one place in the ranking, except for two cases. These larger differences occur because the tool considers all criteria, unlike the company's lexicographic approach with the focus on *Price*. The tool also uses current performance data, while the company evaluation relies on past data. Minimal differences among the lowest-scoring carriers indicate consistent poor performance. Assessing carriers with sustainability criteria incurs additional costs, ranging from \$350 to \$5 per TEU and from 25% to 0.56% of the original cost. These costs are expected due to the comprehensive approach. No difference is noted for the criterion *Confirmed Allocation* across all lanes, but it is advisable to retain it for future use. Identical scores do not affect the overall evaluation, ensuring the robustness and effectiveness of the TOPSIS analysis.

In addition, various sensitivity analyses are conducted. First, the impact of changing the weights of each criterion by ±5% and ±10% on carrier evaluations is assessed. Most shipping lanes show stable rankings with small evaluation changes, confirming the tool's robustness. Secondly, scenario analyses are performed to examine conditions such as equalising category weights, adjusting economic scores, and slightly altering category weights. The results show significant evaluation effects, favouring carriers with strong social and environmental performance. Furthermore, the tool and decision-making process are verified against the established requirements, including constraints and objectives, to ensure they meet operational needs. Validation includes expert feedback and consistency ratio checks of the BWM. Experts find the results convincing but highlight the importance of operational familiarity and the challenge of verifying environmental scores. Finally, from the results, several advantages are identified. The advantages of this structured and systematic approach over current carrier selection methods include its ability to promote sustainable practices, provide clear and consistent evaluations, and improve effectiveness. The biggest advantage is that using the tool in negotiations could provide a competitive market advantage. By presenting carriers with their rankings in comparison to competitors, the company can create a competitive environment. This motivates carriers to offer more competitive pricing or improved terms to win the business. By utilising these insights, the company can ensure more transparent, balanced, well-informed, and strategic carrier selection decisions.

How to implement it, in the case of the company?

The implementation strategy is researched by using qualitative research. It involves integrating the Excel-based tool into Hoyer's operations, ensuring accessibility and ease of use. Regular updates and training sessions are recommended to maintain its relevance and effectiveness. The strategy includes stakeholder engagement, with all relevant departments trained in using the tool, and periodic reviews for continuous improvement. Future steps involve revising the format sent to carriers to gather more accurate data for criteria scores, allowing carriers to provide real data for all social and environmental criteria, thereby replacing assumptions with accurate information. Additionally, the data used for the criterion *Past Performance* needs to be based on current data. This can be achieved by actively monitoring the volume transported by each carrier and cross-referencing it with historical shipping data and customer feedback. Furthermore, migrating the tool to Python for greater automation and flexibility. Implementing this tool significantly advances the company's carrier selection process by integrating sustainability into decision-making and enhancing efficiency. The structured strategy and continuous adaptation ensure the tool's ongoing value. As it evolves, especially with the migration to Python, it will provide even greater efficiency and insights, offering a competitive advantage in the market.

Combining the answers from the sub-questions allows for an answer to the main research question.

How is a carrier for transporting tank containers overseas selected considering the inclusion of sustainability objectives?

This research successfully developed a tool to support the decision-making process for selecting carriers for transporting tank containers overseas, with a focus on sustainability objectives. The tool integrates criteria from the economic, social, and environmental categories, identified through literature review, secondary data analysis and expert interviews. Using the Best-Worst Method (BWM), proven effective for selecting tank container carriers overseas, the criteria are weighted and, in parallel with BWM, carriers are sourced. BWM and carriers' scores are filled in the performance matrix, based on which the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) is applied to evaluate and rank the carriers.

The findings highlight the significance of considering all three sustainability dimensions, with carriers excelling in social and environmental performance often evaluated higher. This balanced approach supports responsible and informed decision-making, allowing decision-makers to select carriers for transporting tank containers over specific shipping lanes. Industry experts have validated the tool's effectiveness, recognising its potential to improve sustainable logistics practices. While the tool meets many needs, future research should explore incorporating operational familiarity and dynamic criteria adjustments to further align with real-world evaluations.

Overall, this study offers a comprehensive and sustainable framework for selecting carriers for transporting tank containers overseas, promoting responsible logistics solutions.

6.2. Discussion

In this section, the discussion is presented. First, the limitations of this research are outlined. Subsequently, the implications of this research are elaborated. Finally, recommendations for future research, practice and implementation are presented.

6.2.1. Limitations

This research has several limitations. First of all, for some carriers, assumptions are made for the score on a particular criterion. These assumptions are based on other carriers' scores on such a criterion, but because of this, they do not reflect the full reality. In addition, although the scores for the criterion *Past Performance* are based on real data, these could give a distorted view. This is because this criterion is based on how much volume a carrier carries of the agreed volume. However, the company always overestimates its volume. Additionally, transporting less volume could also be due to a shortage on the company's side. In short, the scores on this criterion are comprehensive. Scenario analysis two shows that even small changes in the scores of the economic criteria can change the evaluation. The results can therefore give a distorted view of reality when estimates for scores on criteria are used. This highlights the importance of considering and improving accurate scores on all criteria in future research.

Furthermore, decision-makers likely completed the pairwise comparisons with a positive bias, knowing their responses would influence weight derivation. For example, they might have overstated the importance of environmental criteria. Scenario analysis three shows that a slightly higher weight in the environmental category has little effect, but a slight reduction in the economy category has a significant impact. A positive bias might also lower the economic category weight, possibly leading to very different results. Furthermore, only three decision-makers are incorporated into this research because there are no more. However, the weights for some criteria vary per decision-maker. Currently, the average of the three decision-makers is used, but including more decision-makers would yield more reliable results. For example, if decision-maker X scores a criterion much lower, it significantly impacts the result, as it contributes to one-third. However, with 20 decision-makers, an outlier would have less impact, since it only contributes to one-twentieth. More decision-makers help mitigate outliers. Additionally, scenario analyses show that changes in category weights can significantly affect outcomes. Another limitation is that the study did not cover multiple regions of the company. Even though all regions are expected to act with the same interests, the tool is now more focused on one particular region. This may make it harder to use in other regions. More decision-makers from other regions or business units could reduce bias and lead to more reliable results.

External factors, such as ongoing conflicts, Red Sea rate disruptions, and spot price fluctuations, may have influenced the perspectives of the decision-makers, causing them to prioritise criteria differently than under other conditions. For example, these external factors have caused prices to rise significantly, potentially leading decision-makers to value this criterion more than before. *Price* is now a dominant criterion, but scenario analyses show that reducing its weight or that of the economic category significantly affects evaluations. Additionally, the criteria and weights in this research are static. But the market conditions can change continuously. The scenario analyses show that a change in weights or scoring can lead to different evaluations. Therefore, continuous review and adjustment are possible but most of all necessary to maintain relevance. Besides, these continuous changes could cause the tool to be ineffective and make it more important to migrate it to Python.

A final limitation of this study is the inability to incorporate subjectivity, even though it appears to have an effect. Leaving out subjective factors in this study affects the results by not fully capturing what decision-makers truly value. BWM and TOPSIS focus on objective, measurable criteria, but ignoring subjective aspects like familiarity with operations and personal preferences can lead to incomplete and biased carrier evaluations. This might result in choosing carriers that do not fit well with the actual needs and judgements of the decision-makers. Future research should look into how to include subjective criteria to create a more complete and accurate decision-making process.

6.2.2. Implications

This study has important implications for the selection of carriers that transport tank containers overseas. The application of Multi-Criteria Decision-Making (MCDM) methods, specifically the Best-Worst Method (BWM) and the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) prove to be effective for selecting carriers for overseas tank container transport. Additionally, by integrating comprehensive sustainability criteria, this study provides nuanced insights into carrier selection processes. The inclusion of sustainability dimensions: economic, social and environmental, addresses a critical gap in the existing literature, which mainly focuses on operational and economic factors. The study shows that using BWM instead of traditional methods like AHP can be used for decision-making when selecting carriers. Moreover, by broadening the scope to include sustainability considerations, this research offers a comprehensive framework that aligns with current global goals of reducing carbon footprints and promoting responsible business practices. Additionally, the application of BWM and TOPSIS for specifically selecting tank container carriers overseas contributes to the literature, as this area has not been previously explored. Practically, this research offers logistics managers and decision-makers a refined approach to evaluate and rank carriers based not only on costs but also on their broader impact on the environment and society. This approach not only mitigates operational risks but also contributes to the sustainable development goals of the logistics sector.

In conclusion, this thesis contributes a methodologically robust and practically relevant framework for selecting carriers for overseas tank container transport, thereby advancing both academic understanding and industry practices towards more sustainable logistics operations on a global scale.

6.2.3. Recommendations

Based on this research some recommendations can be addressed. There are recommendations for future research, for practice and for implementation.

6.2.3.1. Future research

Future research could significantly benefit from developing methods that incorporate subjective criteria, such as surveys of stated preferences or expert opinions. This would provide a more comprehensive assessment of carrier performance by including both objective measures and subjective considerations in BWM and TOPSIS. Moreover, future research should explore how to address rapidly changing issues due to external factors, considering their impact and how to account for them.

Expanding the study to different regions within the company's operational domain would be valuable. Comparative analyses across regions can enhance understanding of carrier performance variations and assess the evaluation tool's effectiveness in diverse environments. Including diverse regions would offer insights into region-specific challenges and requirements, facilitating the adaptation of evaluation tools while ensuring consistency and comparability.

Involving multiple decision-makers in further research is advisable. Currently, there are three, but increasing the number of decision-makers could produce more reliable results. Including decision-makers from different regions or business units would improve the findings of the study. Conducting focus groups or workshops with these decision-makers could clarify their perspectives, preferences, and criteria for carrier selection, improving the evaluation process's accuracy and reliability.

Finally, further research could validate the results by applying other MCDM methods such as AHP. Using different MCDM methods can enhance the accuracy and reliability of the evaluations.

6.2.3.2. Practice

A recommendation for further research for the company is to seek actual data for the criteria scores where assumptions are previously made. By revising the format sent to carriers, this information can be directly gathered from them, replacing assumptions with real data. Additionally, all social and environmental criteria should be included in this format to save the company the effort of searching for this information. Criteria such as CO_2 *Emission per Shipment* and *Service* should be added so carriers can provide this data themselves.

Additionally, to mitigate bias, it is essential to implement measures that reduce potential positive biases in decision-makers pairwise comparisons. Providing clear instructions and structured decision-making protocols can promote more objective evaluations.

The data used for the criterion *Past Performance* must be improved. Currently, these scores are based on data that may not accurately reflect reality. Under or over-performance might be due to either carrier performance or inaccurate estimates by Hoyer. To prevent this, Hoyer should actively and accurately monitor the volume transported by each carrier and make realistic estimates, which will be easier with up-to-date data. Cross-referencing past volume scores with historical shipping data or customer feedback can further enhance the accuracy of this criterion.

Furthermore, developing a streamlined platform or tool for automated evaluation based on input criteria, which adjusts as conditions change, would increase efficiency and practicality in decision-making. Implementing TOPSIS in Python could facilitate this. Using Python, many manual actions can be automated, offering flexibility, quick decision-making, and scalability. Input and output data can still be stored in Excel, but the evaluation will be done in Python. The existing TOPSIS code can be slightly adjusted and then used for this purpose.

Finally, the company could optimise the use of a selected group of carriers by strategically distributing volumes. By allocating volumes to a smaller number of carriers, fewer carriers need to be selected, which can enhance overview, structure, and goal achievement. Working with fewer carriers can lead to better agreements and help achieve company goals more effectively.

6.2.3.3. Implementation

Implementing the tool enables the company to select carriers based on increasingly important sustainability objectives, contributing to a structured and balanced decision-making process. It ensures consistency across regions by providing a common evaluation framework for all decision-makers. There is a risk that costs for procuring carriers will be higher than before, because no longer will only the cheapest carrier be chosen. However, by taking other criteria into account, gains can be made in other areas and any losses can be offset or even heavily outweighed by this, for example. To integrate the tool into the company's decision-making process, the following steps need to be taken.

Step 1 - Store criteria, their weights, tool and output file

Firstly, the Excel file that already contains the identified criteria and their weights should be stored on the global disk of the company. Within this Excel file the BWM calculations are also included. So in case some weights need to be adjusted or other criteria come in place, this can be adjusted within this Excel file. In addition, the Excel file in which the tool is made should also be stored on the global disk of the company. Lastly, an output file should be created on the global disk in which the evaluation per shipping lane should be stored.

Step 2 - Ask carriers to provide input on the CO_2 Emission per Shipment

Carriers should be asked to provide their CO_2 *Emission per Shipment* over each shipping lane over which they offer a service. The company can also look this up itself, but this is expected to be time-consuming. It is therefore advisable to try this from the carriers first.

Step 3 - Consolidate carriers data

The data that is already provided by the carriers plus the extra data on CO_2 *Emission per Shipment* should be consolidated into one Excel file.

Step 4 - Consolidate data not delivered by the carriers

A separate Excel file should be created into which the company should store the data on *Past Performance*. Furthermore, the company should also store the calculations and scores of the multiple carriers on the social criteria. The same should be done for the environmental criteria, except for the *ETS Fee* and CO_2 *Emission per Shipment* as these scores are already provided by the carriers.

Step 5 - Link all the data files to the evaluation tool

Now that all the input data is ready it can be loaded in the Excel file of the tool. To do so, some constraints have to be constructed within the Excel file of the tool. These constraints have to make sure that the data for the shipping lane that needs to be evaluated is loaded. So that the right carriers are evaluated considering their scores on the economic, social and environmental criteria. Besides, these constraints need to make sure that in case only three carriers are offering a service the tool tab for three carriers will be used instead of the one for five carriers for example.

Step 6 - Pilot testing

To make sure that no mistakes are made and the tool works as it is supposed to work, the three decision-makers should participate in a pilot test of the tool. This contributes to minimising the risk of making mistakes when loading the data and storing the evaluations. For the pilot, they should each apply the tool to three different shipping lanes. Their feedback should be gathered on potential issues, usability and results. This feedback has to be discussed and potential improvements should be processed before continuing to large scale.

Step 7 - Evaluate on a large scale

After the pilot, it is assumed that the tool can be applied to all the shipping lanes. By hand, a certain shipping lane will have to be chosen. The Excel file will then load the correct data itself and an evaluation will follow from this. This evaluation will have to be copied and pasted by hand into the created output file. By letting a second person look at the final evaluation extraordinary evaluations will then probably be noticed and checked minimising the risks of mistakes.

Step 8 - Send out evaluations to Carriers

The output Excel file could be sent out to the carriers. If desired, it is possible to filter it out per carrier so that each carrier can only view its own evaluations per offering shipping lane. In addition, a blank version of the tool can also be sent to the carriers so they can see how the evaluation is put together and where they can best improve. The carriers can provide potential improvements.

Step 9 - Update tool

If a carrier shares updated information during the process, the data will have to be updated and the steps above will have to be followed again. Finally, a final decision can be made on which carriers to select. Furthermore, the weights of the categories and criteria should be evaluated before the start of a tender process. It is assumed that these criteria and weights will not change much. However, it is important to check them regularly. The weights should be discussed and evaluated with the multiple decision-makers and regions. Due to certain global issues or circumstances, some criteria could become much more important. If this is the case the weights should be updated by performing the BWM again. Hereafter, these weights need to be updated in the TOPSIS. Additionally, the scores of the carriers on the social and environmental criteria should be updated yearly as the sustainability reports of the carriers are also released annually.

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A

Interview Guide

In this appendix, the listed interview questions along with their structure are presented. It is worth noting that the questions are presented in English. Nevertheless, it is important to highlight that not all interviewees preferred the interviews to be conducted in English. When this preference was evident, the questions were posed in Dutch. Additionally, a standard set of general information was collected at the outset of each interview, and this uniform data is outlined below.

General information

1. Date
2. Time
3. Location
4. Function
5. Employment Tenure
6. Purpose of the Interview
7. Topic

Questions on current carrier selection

1. *Can I record the interview?*
2. What is your function within Hoyer?
3. How are you involved in the carrier selection process?
4. Do you know how the carrier selection process is currently going?
   (a) If yes, could you elaborate a bit more on that?
5. In terms of carrier selection, what criteria or factors are currently considered when selecting a carrier? (e.g., services, costs)
   (a) Do these criteria determine the priority of a carrier?
   (b) What is the order of these criteria?
6. Are these criteria compensatory or not?
   (Non-compensatory methods are often used when certain criteria are considered essential or deal-breakers, and there is no flexibility in allowing trade-offs between them.)
7. How does the company ensure that the selected carriers comply with relevant regulations (regulations related to sustainability, for example)?
   (a) Are KPI's used?

8. Are there specific customer requirements or priorities that influence the carrier selection decisions?
    (a) If so, how are they taken into account?
9. Are there any other underlying factors that influence the carrier selection process?
10. Are there any technological tools or software that you utilise to enhance the efficiency of carrier selection?
11. Do you collaborate with different departments to ensure a cohesive and streamlined approach to carrier selection across different areas?
    (a) If so, which departments?
    (b) If so, are they constantly updated?
    (c) If so, how would they think about sustainability?
12. From your perspective, how does the current carrier selection process impact the company's organisation?
    (a) What improvements do you propose in this regard?
13. Who do you think is responsible for the carrier selection?
14. What department has the largest influence on carrier selection?
    (a) Why them?
    (b) Could this be changed?

Questions related to Sustainability

1. Can you describe the current level of consideration for sustainability in the carrier selection process?
2. Are there any existing sustainability initiatives within the company, even if not directly related to carrier selection?
    (a) If so, are there specific tools or methodologies used to evaluate the carbon footprint or other environmental aspects of carriers?
3. In your opinion, what are the main challenges in integrating sustainability into carrier selection?
4. Do you see any untapped opportunities where sustainability could be easily incorporated into the current process?
5. How can the company track and report on progress in integrating sustainability into the carrier selection process?
6. Are there stakeholders or departments within the company that should be involved in discussions about incorporating sustainability into carrier selection?

Other questions

1. Who else do you think is a good idea to interview?

B

Interview Results

In this appendix, short summaries of the interviews are presented. All the interviews are recorded and transcribed. Given that the interview duration was on average 45 minutes, a concise summary has been generated from the transcription.

B.1. Procurement Manager

Date: 14-03-2024
Time: 11:00-12:00
Location: Hoyer
Function: Procurement Manager Europe & Africa
Employment tenure: 4 Years
Purpose of the interview: Information on the process, existing criteria and sustainability
Topic: General Overview

The interviewee, identified as a procurement manager for Europe and Africa at Hoyer, discusses his role in carrier selection and the current process. He mentions being responsible for managing a spend of $80 million, mostly comprising sea freight. The interviewee collaborates with his team to determine carrier selection criteria based on internal qualifications within Hoyer. The process involves defining requirements before approaching carriers, considering the match between requested services and the carrier's offerings, and determining short- and long-term strategies. The current criteria for carrier selection include financial, operational, product-related factors, price, and acceptance of contractual agreements, but no specific order or weighting is given to these criteria. The interviewee mentions that costs currently guide carrier selection decisions.

The interviewee notes that environmental considerations are not included in the selection process, although social aspects are addressed through a code of conduct for ethical business practices. Most multinational companies have their sustainability requirements, but environmental sustainability is seen as an area for improvement. The interviewee highlights the challenge of integrating sustainability into carrier selection due to the complexity of catering to diverse customer demands and the limited impact of Hoyer's volume on initiating sustainability initiatives. He suggests that the main challenge lies in making sustainability measurable and proposes involving quality management and innovation departments to develop metrics and integrate sustainability into operations and commercial strategies.

Regarding future interviews, the interviewee suggests involving SHEQ (safety, health, environment, and quality) and innovation departments to discuss sustainability integration further.

The interview sheds light on Hoyer's carrier selection process, highlighting the current focus on cost considerations and the challenges of integrating sustainability. While environmental sustainability is recognised as an area for improvement, making it measurable remains a significant challenge. The interviewee emphasises the importance of involving various departments to address this issue effectively.

B.2. Global Head of Procurement Overseas

Date: 19-03-2024
Time: 11:00-12:00
Location: Hoyer
Function: Head of Procurement Overseas
Employment tenure: 10 Months
Purpose of the interview: Information on the process, existing criteria and sustainability
Topic: General Overview

In the interview with the Global Head of Procurement Overseas, responsible for carrier selection at Hoyer, a detailed insight is provided into the selection process and the considerations involved. This person leads a team of 20 professionals spread across various locations worldwide, including Rotterdam, Dubai, Singapore, Shanghai, Houston, and São Paulo.

The selection process begins with a tender, considering criteria such as price, transit time, transhipment capabilities, and past experiences with shipping lines. It is noted that the business and operations within Hoyer have different perspectives on the number of nominated carriers. While the business desires multiple options, the Global Head of Procurement Overseas strives for fewer nominations, especially for routes with lower container volumes (below 50 TEU).

Key criteria in the selection include price, transit time, transhipment ports and shipping lane performance. Transit time is considered particularly important by the business, while the transhipment port has less influence, except for specific routes. Sustainability is also beginning to play a growing role, although challenges exist regarding the measurability and reliability of sustainability claims.

Technological tools are currently not actively used due to data quality issues, but improvements are suggested. There is increasing attention to sustainability within Hoyer, but integrating it into the selection process requires reliable measurements and stakeholder engagement.

The Global Head of Procurement Overseas shares some changes implemented in the current tender process, such as more streamlined processes and a greater focus on accurate volume forecasts. He also suggests interviewing Ties (sustainability) and sales manager Michel de Kramer for broader perspectives.

In conclusion, the interview provides an in-depth insight into the complex process of carrier selection at Hoyer, weighing various criteria and perspectives to make the best decisions for the company.

B.3. Category Manager Ocean Freight

Date: 26-03-2024
Time: 16:00-17:00
Location: Teams
Function: Category Manager Ocean Freight
Employment tenure: 5 Months
Purpose of the interview: Information on the process, existing criteria and sustainability
Topic: General Overview

The Category Manager for Ocean Freight at Hoyer, plays a pivotal role in managing the global tender processes for carrier selection. Her responsibilities encompass receiving, synthesising, and incorporating feedback from various regions to inform the decision-making process. Key factors considered in this feedback include transit time, operational issues, and pricing, with no predefined selection criteria in place. Regions nominate preferred carriers based on their assessments, particularly for smaller volume forecasts, while larger volumes involve region-based nominations.

The carrier selection process revolves around matching target rates set by Hoyer, with carriers competing to secure business by meeting these rates or even offering lower ones to demonstrate their eagerness for partnership. While customer preferences and sales team input occasionally influence decisions post-tender, the priority is given to preferred carriers, albeit contingent on their ability to match target rates.

Technology plays a role in bench marking through tools like Xeneta, and there is a desire for a dedicated tender tool to streamline processes and move away from reliance on spreadsheets. The Global Head of Procurement Overseas, as the final decision-maker, often seeks input from regions before making decisions.

Despite acknowledging the importance of sustainability, it is not currently factored into the carrier selection process. However, there is a sustainability department tasked with assessing carrier sustainability, indicating a potential avenue for future integration.

Challenges in integrating sustainability into carrier selection include customer reluctance to bear additional costs for greener transport. However, the sustainability department's involvement underscores the company's commitment to addressing environmental concerns.

Looking ahead, improvements for the next tender include optimising communication channels and ensuring clarity in documentation to avoid misinterpretation. Feedback from regions remains paramount, and preparations for the next tender are set to commence shortly.

C

Flow Chart Tender Process

In this appendix, a general overview of the tender process is presented. The flow chart of the tender process can be seen in Figure C.1. Each phase within this process is discussed separately.

C.1. Tender process

The person taking action and being responsible for certain tasks within the company is also reflected in the flow chart by the coloured speech balloon. The flow chart is divided into two ”rows.” Everything in the top row is processes or decisions performed by the company. The bottom row reflects processes and decisions performed by a carrier. Furthermore, there are four ”columns,” four vertical sections, in the flow chart. These indicate the four general phases of the tender. It starts with preparing the tender, after which carriers are invited to participate in the tender, then the price, among other things, is negotiated, and finally, the outcomes of the tender are implemented.

From the coloured balloons, it can be seen that the Global Head of Procurement Overseas is mainly involved in the decisions. This is because this person is the final decision-maker and he oversees everything. In case things are going wrong he will step in, but otherwise, the regions and the category manager will mainly organise the tender. It is crucial to recognise that all three stakeholders in the tender process hold equal importance and have an equal voice, even if it may not appear so. Each stakeholder influences the decision, making them all decision-makers. Additionally, they operate with the understanding that business expectations must be met, further justifying their equal say. Despite having varying degrees of influence at different stages of the tender, the Global Head of Procurement Overseas ultimately makes decisions based on the trusted information provided by the other two stakeholders, showing their equal importance.

C.1.1. Preselection

In the initial phase, the tender is being prepared. During this phase, the regions take the lead. They will forecast the expected volumes in collaboration with their internal teams, such as sales and operations. Additionally, the regions will assess the performance of carriers from the previous contract term. A procurement strategy will also be established, which may involve short-term or long-term procurement. While each region will develop its strategy, there will also be a unified approach for all regions. Based on this, they will compile a list of carriers to invite to participate in the tender. It is important to note that each region is responsible for its export shipping lanes.

Moreover, the tender documents such as the NDA, RFP & RFQ will be prepared before inviting carriers. This is currently being done by the category manager ocean freight to create a centralised approach.

C.1.2. Carrier invitation & participation

In the second phase, carriers are invited to participate in the tender. The Category Manager of Ocean Freight initiates this by sending the initial tender documents to all carriers. Additionally, the category manager is responsible for receiving and facilitating feedback from each region, consolidating it into a single format to communicate with the carriers centrally.

Carriers will review the initial tender documents to decide if they wish to continue participating in the tender. If they choose to proceed, the company will then dispatch the full tender documents, requesting quotations. Upon approval, carriers will submit their initial bids for specific shipping lanes. The company will evaluate these bids to determine their potential. If a carrier and its bids are considered promising, the company will agree to further negotiations in the next phase.

C.1.3. Negotiation & Contract

In the third phase, there is an opportunity to negotiate and potentially reach a contract. Initially, the company allows the carriers to submit a second bid. This is facilitated by the company displaying its target rates to the carriers, which are determined using the benchmark tool ”Xeneta.” Following this, there is also an opportunity for further negotiation.

The regions have a list of global port pairs with associated costs and information. They will consult internally with teams such as sales and operations to decide which carriers they would like to nominate for specific shipping lanes in their region. The regions then determine whether to accept an offer. If accepted, the region will allocate a certain volume to a carrier for its export shipping lanes. This decision is communicated to the carrier, and if an agreement is reached between the company and the carrier, a contract will be signed by both parties to confirm the outcome of the tender.

C.1.4. Execution

After the contracts are signed, the rates set for specific shipping lanes are uploaded into ”VCM,” the system used to book shipments. The Rotterdam region is responsible for uploading all tender outcomes. Previously, each region handled this individually, but since the last tender, which concluded at the end of March, this process has been centralised using ”bulk uploading.” Bookings can then be made using the rates and shipping lanes established in the tender. When a booking request is made, the carrier must still confirm the booking to ensure there is space available on the ship for a tank container.

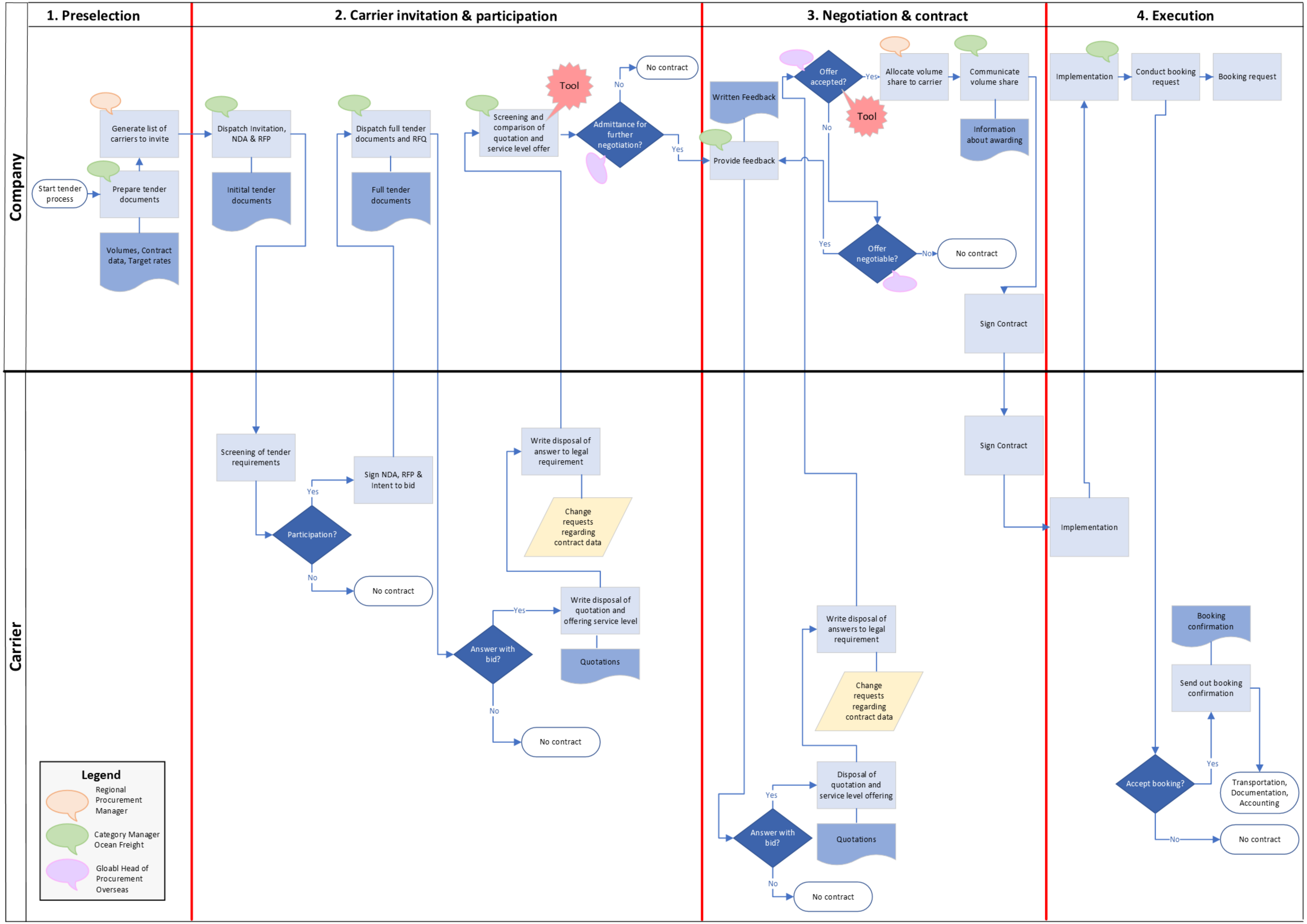


Figure C.1: Flow chart tender process

D

Criteria Description and Selection

In this appendix, all identified criteria, from literature and experts, are presented first. Secondly, the survey to limit the identified criteria is discussed. Finally, the results of this survey are presented followed by the final list of criteria.

D.1. List of identified criteria

The criteria that are identified are presented in Table D.1. The criteria are identified from literature and expert interviews [55, 6, 56, 27, 1, 41, 4, 10, 15, 26, 33, 20, 61]. Many more criteria were found, but numerous criteria of these had similarities with other criteria. As the list of criteria is very long they are categorised into three different categories. These categories are based on the dimensions within sustainability, namely economic, social and environmental discussed in section 2.3. Many criteria found in the literature are often already divided into one of these categories. In addition, the criteria that fall within the social and environmental category clearly belong there. However, this is different for the economic category. Costs, for example, fall into this category. In addition, also other criteria fall into this category that, for example, ensure value creation or optimal use of certain resources. As mentioned in section 2.3 economic criteria relate to enduring financial viability, optimal resource utilisation, and value generation while maintaining fiscal stability. The Table below presents all the identified criteria and the categories in which they belong.

Table D.1: List of identified criteria

Criteria	**Sub-criteria**	**Definition**
	C1: Service	The number of ports of call a carrier uses to transport a tank container.
	C2: Rate Validity	The period for which the agreed rate is valid.
	C3: Transit-time	The time a carrier needs to move goods from origin to destination, covering the entire journey including any delays or layovers.
	C4: Confirmed Allocation	The guaranteed space for cargo on the transport vessel
	C5: Free Time	The duration where shippers can use carrier facilities without extra charges, enhancing supply chain efficiency and minimising costs.
	C6: Price	The cost of the transport service.
	C7: IMO Surcharge	The extra fee imposed by carriers for transporting goods classified as dangerous by the International Maritime Organisation. It is negotiable.
	C8: ETS Fee	A charge imposed by carriers to comply with the Emissions Trading Systems (ETS), aiming to reduce greenhouse gas emissions. It reflects the carrier's costs for carbon allowances or offsets.
	C9: Demurrage costs	Refer to charges incurred by shippers for exceeding the allotted time for cargo loading or unloading at a port. These charges compensate carriers for terminal facility usage beyond the agreed free time.
Economic	**C10:** Reliability	Refers to how consistently and dependably a carrier adheres to schedules, meets delivery deadlines, and provides accurate shipment information.
	C11: Carrier Reputation	Refers to the overall image of a carrier based on factors such as service quality, reliability, safety, customer satisfaction, and ethical behaviour.
	C12: Geographical Coverage	Refers to the extent of a carrier's transportation network, including the range of destinations and ports served.
	C13: Communication	Refers to a carrier's effectiveness in providing timely updates and support to customers throughout the transportation process.
	C14: Past Performance	The amount of volume a carrier is currently transporting compared to the awarded volume to that carrier
	C15: Frequency of service	Refers to how often a carrier operates transportation services on a specific route or trade lane.
	C16: Transshipment Port	Refers to an intermediate hub where cargo is transferred between vessels during its journey.

Continued on next page

Table D.1 – continued from previous page

Category	Criterion	Definition
	C17: Carrier Experience	Refers to a carrier's accumulated knowledge and proficiency in providing transportation services over time.
	C18: Shipping lane	Refers to a defined sea route vessels follow to transport goods between ports.
	C19: Payment-term	Refers to the agreed-upon terms for payment of transportation services provided by the carrier.
Social	**C1:** Work Safety	Prevention of workplace accidents and ensuring a secure work environment through safety protocols, equipment, and training.
	C2: Labour Health	The well-being of employees, encompassing physical and mental aspects.
	C3: Respect for ethical issues and legal compliance	The commitment of a carrier to moral principles and adherence to laws and regulations.
	C4: Staff Training	Refers to educating and developing employees to enhance their skills and knowledge.
	C5: Employee interests and rights	Consideration for the rights and interests of employees.
Environmental	**C1:** CO_2 Emission per Shipment	Refers to the carbon dioxide released during transportation.
	C2: Fuel Type	The type of fuel used by the transport. It involves considering cleaner and renewable fuel sources to minimise environmental impact and meet emission regulations, promoting sustainability in maritime transport.
	C3: Sustainability Rating (EcoVadis)	Refers to the evaluation from EcoVadis, an independent sustainability rating platform. It assesses a carrier's performance across environmental, social, and ethical criteria.
	C4: Control of Pollution	Refers to the actions taken by carriers to reduce environmental pollution during transportation. This involves employing clean technologies and adhering to regulations.
	C5: Green/Sustainable image	Denotes the reputation of a carrier for environmental friendliness and sustainability.
	C6: Compliance with sustainability regulations	Indicates a carrier's adherence to environmental, social, and ethical standards set by regulations. This includes emissions control, waste management, and labour practices.
	C7: Green R&D and innovation	Refers to the efforts of a carrier in researching and innovating eco-friendly transportation solutions. It includes developing technologies to reduce emissions and promote sustainability.
	C8: Environmental Commitment	Refers to a carrier's pledge to sustainability and reducing its environmental impact. It includes actions to lower emissions and conserve resources.

Continued on next page

Table D.1 – continued from previous page

Category	Criterion	Definition
	C9: Energy and Resource Efficiency	Refers to a carrier's adeptness in using resources and energy to maximise productivity while minimising waste. This involves optimising fuel consumption and resource management.
	C10: Green Finance	Refers to financial support for environmentally sustainable initiatives in shipping. It involves investing in projects to reduce emissions and enhance energy efficiency.

D.2. Survey to limit the criteria

From Table D.1 it can be seen that the list of criteria is very long. To use the Best-Worst Method (BWM) and keep the study manageable, this list is shortened. It is therefore decided to use a survey that is completed by the three experts, also known as the decision-makers in carrier selection, to arrive at fewer criteria. The experts that are asked to fill in the survey are presented in Table D.2. They are asked to fill in the survey independently from each other because it is expected that they influence each other's decisions and choices.

Table D.2: Overview of experts for criteria selection

Person	Function	Respondent number
Person A	Global Head of Procurement overseas	1
Person B	Procurement Manager Europe & Africa	2
Person C	Category Manager Ocean Freight	3

The survey that is used to find the most important criteria out of the whole list of criteria consisted of three different parts. The same parts as presented in Table D.1 are used. These parts are economic criteria, social criteria and environmental criteria. For each criterion in each part, the respondent is asked to decide if the criteria should be *Included*, *Maybe Included* or *Excluded* for selecting a carrier. The options and their meaning are as follows:

- **In:** This means that this criterion should definitely be included in the process of selecting a carrier.
- **Maybe:** This means that this criterion might have to be taken into account when selecting a carrier.
- **Out:** This means that this criterion should definitely NOT be included in the process of selecting a carrier

Furthermore, for each part, there is an option for the respondent to mention missed criteria or other comments on the question or criteria.

D.3. Results survey to select criteria

The results of the survey that is filled in by the three decision-makers are presented in Table D.3.

Table D.3: Results survey to select criteria

Category	Criterion	Respondent 1	Respondent 2	Respondent 3
Economic	**C1:** Service	In	In	In
	C2: Rate validity	Maybe	In	In
	C3: Transit-time	In	In	In
	C4: Confirmed Allocation	In	In	In
	C5: Free time	Maybe	In	Maybe
	C6: Price	In	In	In
	C7: IMO Surcharge	In	In	In
	C8: ETS Fee	Maybe	In	In
	C9: Demurrage costs	Maybe	In	Maybe
	C10: Reliability	Maybe	In	Maybe
	C11: Carrier Reputation	Maybe	Maybe	Maybe
	C12: Geographical coverage	Out	In	In
	C13: Communication	Maybe	Maybe	Maybe
	C14: Past Performance	In	Maybe	Maybe
	C15: Frequency of service	Maybe	In	Maybe
	C16: Transshipment Port	Maybe	In	In
	C17: Carrier experience	Maybe	Out	In
	C18: Shipping lane	Out	In	In
	C19: Payment-term	Maybe	In	Maybe
Social	**C1:** Work safety	In	In	Maybe
	C2: Labour Health	In	In	Maybe
	C3: Respect for ethical issues and legal compliance	In	In	Maybe
	C4: Staff training	Maybe	Maybe	Maybe
	C5: Employee interests and rights	In	In	Maybe
Environmental	**C1:** CO_2 Emission per Shipment	In	In	Maybe
	C2: Fuel Type	Maybe	In	Maybe
	C3: Sustainability rating (EcoVadis)	Maybe	In	Maybe
	C4: Control of Pollution	Maybe	In	Maybe
	C5: Green/Sustainable image	Maybe	In	Maybe
	C6: Compliance with sustainability regulations	In	In	Maybe
	C7: Green R&D and innovation	Maybe	In	Maybe
	C8: Environmental commitment	Maybe	In	Maybe
	C9: Energy and Resource Efficiency	Maybe	In	Maybe
	C10: Green Finance	Maybe	In	Maybe

From the results of the survey, it can be seen that there are many differences between the different respondents. To determine which criteria to include it is decided to include a criterion when all three respondents rated a criterion as **In** or when two of the three respondents rated a criterion as **In** and the third one rated it **Maybe**.

D.4. Final selected criteria

Furthermore, four exceptions are made to the rule stated above. Firstly, from the interviews, it is noticed that the *Past Performance* of a carrier plays a role in carrier selection. However, from the survey results it can be seen that the decision-makers do not find it important. The final decision-maker (person A) although, rated this criterion as **In**. Therefore it is decided, to still include this criterion. Secondly, it is decided to include the criterion *Fuel Type* as this criterion is often mentioned in the literature and also in the interviews. Additionally, the criterion *ETS Fee* is moved to the environmental category as it is noticed after the survey that this criterion is more related to the environment. The criterion is quantified in dollars, but the fee aims to address environmental concerns. Lastly, the criterion *Transshipment Port* is not chosen to overcome double counting. If a transshipment port is used this is already taken into account by the criterion *Service* as this criterion reflects the number of ports of call. If a transshipment port is used then automatically one more port of call is added.

As the list of criteria is still on the long side, it is decided to stick to the three categories into which the criteria are divided. The list of the final criteria that are chosen to include in this research is presented in Table D.4.

Table D.4: Final list of criteria to include

Category	**Criterion**
Economic	**C1:** Service
	C2: Rate Validity
	C3: Transit-time
	C4: Confirmed Allocation
	C5: Price
	C6: IMO Surcharge
	C7: Past Performance
Social	**C8:** Work Safety
	C9: Labour Health
	C10: Respect for ethical issues and legal compliance
	C11: Employee interests and rights
Environmental	**C12:** CO_2 Emission per Shipment
	C13: Compliance with sustainability regulations
	C14: Fuel Type
	C15: ETS Fee

E

Weights of the critera

In this appendix, a comprehensive overview is provided of the weights assigned to all the criteria selected in Appendix D using the BWM method. The pairwise comparisons and final weights for all analyses are presented, followed by a summary of the weights for all criteria.

E.1. Results Pairwise Comparisons

Each decision-maker filled in the survey independently from the other decision-makers. Within the survey, they are asked to fill in the question for the pairwise comparisons for all four analyses. This process resulted in two pairwise comparisons per decision-maker per analysis. It is important to note that for each pairwise comparison and analysis, the consistency ratios were checked. However, not all consistency ratios were acceptable. Some notable inconsistencies were found in the responses from the decision-makers. For example, respondent 2 identified the criterion *Price* as the best criterion in the second analysis and *Past Performance* as the worst criterion. However, the respondent indicated that *Price* is ”moderately more important” than *Past Performance*, which was unexpected. Upon discussing this with the respondent, it was clarified that *Price* should be considered very strong or absolutely more important than *Past Performance*. After reviewing and adjusting all the respondents’ answers, all consistency levels became acceptable. It is important to note that an error was made in the pairwise comparisons. The pairwise comparison for respondent one in Table E.1 was not thoroughly checked. It was later discovered that the best-to-worst and worst-to-best comparisons did not receive the same preference. The value should be 8, as now reflected in Table E.1, but it was initially recorded as 7. However, this mistake does not significantly affect the overall results. The other final results of the pairwise comparisons are shown in the Tables below.

E.1.0.1. Analysis 1: Pairwise Comparison

Table E.1: Pairwise Comparisons Results - Analysis 1

Resp.	Best Criterion	Worst Criterion	Vector A_B	Vector A_W	Weights	CR	Threshold
1	Economic	Social	{1,8,7}	{8,1,2}	*Economic*: 0.778 *Social*: 0.100 *Environmental*: 0.122	0.107	0.131
2	Economic	Social	{1,6,4}	{6,1,2}	*Economic*: 0.704 *Social*: 0.111 *Environmental*: 0.185	0.067	0.133
3	Economic	Social	{1,9,4}	{9,1,4}	*Economic*: 0.726 *Social*: 0.071 *Environmental*: 0.202	0.097	0.136

E.1.0.2. Analysis 2: Pairwise Comparison

Table E.2: Pairwise Comparisons Results - Analysis 2

Resp.	Best Criterion	Worst Criterion	Vector A_B	Vector A_W	Weights	CR	Threshold
1	Price	Rate Validity	{6,9,7,5,1,6,5}	{5,1,4,6,9,5,6}	*C1*: 0.096 *C2*: 0.038 *C3*: 0.082 *C4*: 0.115 *C5*: 0.459 *C6*: 0.096 *C7*: 0.115	0.292	0.352
2	Price	Past Performance	{3,2,3,4,1,2,8}	{2,2,4,2,8,2,1}	*C1*: 0.119 *C2*: 0.179 *C3*: 0.119 *C4*: 0.080 *C5*: 0.269 *C6*: 0.179 *C7*: 0.045	0.071	0.341
3	Price	Past Performance	{5,8,2,4,1,2,9}	{3,4,9,5,9,9,1}	*C1*: 0.081 *C2*: 0.050 *C3*: 0.202 *C4*: 0.101 *C5*: 0.335 *C6*: 0.202 *C7*: 0.030	0.319	0.352

E.1.0.3. Analysis 3: Pairwise Comparison

Table E.3: Pairwise Comparisons Results - Analysis 3

Resp.	Best Criterion	Worst Criterion	Vector A_B	Vector A_W	Weights	CR	Threshold
1	Work Safety	Employee interests and rights	{1,1,1,1}	{1,1,1,1}	*C8*: 0.25 *C9*: 0.25 *C10*: 0.25 *C11*: 0.25	0	0
2	Respect and legal compliance	Employee interests and rights	{1,1,1,1}	{1,1,1,1}	*C8*: 0.25 *C9*: 0.25 *C10*: 0.25 *C11*: 0.25	0	0
3	Respect and legal compliance	Employee interests and rights	{1,1,1,1}	{1,1,1,1}	*C8*: 0.25 *C9*: 0.25 *C10*: 0.25 *C11*: 0.25	0	0

E.1.0.4. Analysis 4: Pairwise Comparison

Table E.4: Pairwise Comparisons Results - Analysis 4

Resp.	Best Criterion	Worst Criterion	Vector A_B	Vector A_W	Weights	CR	Threshold
1	CO_2 Emission per Shipment	Fuel Type	{1,1,1,1}	{1,1,1,1}	*C12*: 0.25 *C13*: 0.25 *C14*: 0.25 *C15*: 0.25	0	0
2	Compliance with regulations	ETS Fee	{1,1,1,1}	{1,1,1,1}	*C12*: 0.25 *C13*: 0.25 *C14*: 0.25 *C15*: 0.25	0	0
3	ETS Fee	Fuel Type	{2,4,7,1}	{6,4,1,7}	*C12*: 0.298 *C13*: 0.149 *C14*: 0.064 *C15*: 0.489	0.214	0.246

As three decision-makers performed pairwise comparisons for the four analyses, this resulted in three weights for each category and three weights for each criterion in each analysis. However, to be able to work with the weights and use them in TOPSIS, these weights need to be aggregated. The weights have been aggregated using the geometric mean method, as explained in chapter 5.

E.1.1. Overview all criteria weights

An overview of the final criteria weights per decision-maker, the final aggregated weights per criterion and the evaluation of the weights are presented in Table E.5. From this Table, it can be seen that all the economic criteria are the most important as C_1 till C_7 are evaluated as the top seven criteria. All social criteria, C_8 till C_{11} are the least important, except for C_9. Lastly, the environmental criteria, C_{12} till C_{15}, are the most important after the economic criteria, except for C_{14}. This criterion is the least important criterion of all criteria.

Table E.5: All criteria weights with evaluation

Weights	*C1*	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*	*C9*	*C10*	*C11*	*C12*	*C13*	*C14*	*C15*
DM1	0.074	0.030	0.064	0.089	0.357	0.074	0.089	0.025	0.025	0.025	0.025	0.031	0.031	0.031	0.031
DM2	0.084	0.126	0.084	0.063	0.189	0.126	0.032	0.028	0.028	0.028	0.028	0.046	0.046	0.046	0.046
DM3	0.059	0.037	0.146	0.073	0.243	0.146	0.022	0.018	0.018	0.018	0.018	0.060	0.030	0.013	0.099
Final Aggregated	0.096	0.083	0.107	0.098	0.165	0.116	0.074	0.023	0.023	0.023	0.023	0.046	0.038	0.031	0.052
Evaluation	5	6	3	4	1	2	7	13	11	12	14	9	10	15	8

F

Quantification of criteria

In this appendix, the quantification for various criteria is detailed. First, the economic criteria requiring quantification are addressed. Next, the social criteria and their quantification are elaborated upon. Lastly, the quantifying of the environmental criteria is described.

F.1. Economic criteria

The economic criteria that need to be quantified are *Service*, *Rate Validity* and *Past Performance*.

F.1.0.1. C1. Service

Service as a criterion reflects the number of ports of call (number of stops). A port of call is a harbour where a ship stops to take on supplies, undergo maintenance, or handle cargo. Fewer ports of call boost efficiency as it minimises delays and days. It also reduces costs such as port fees, fuel, and handling charges. This simplification of logistics leads to more predictable delivery schedules. For the shipping lanes that are used for this research, the number of ports of call is given by the different carriers and a lower value is thus preferred.

F.1.0.2. C2. Rate Validity

Rate validity is already quantified in the number of months that a rate is valid. The rate validity thus remains the same for a certain carrier for each shipping lane. The rate validity for each carrier is presented in Table F.1. Ten carriers are participating in the tender so therefore the rate validity is given for those carriers. Furthermore, a higher rate of validity is preferred if a shipping lane does not include a port in Asia. The market in Asia is always fluctuating so a company wants to be able to directly respond to that. If an Asia port is included in a shipping lane then a lower rate validity is preferred. It is important to note that these values are subject to frequent changes, necessitating regular reviews.

Table F.1: Rate Validity

Carrier	Rate Validity (#Months)
Carrier 1	3
Carrier 2	6
Carrier 3	3
Carrier 4	3
Carrier 5	12
Carrier 6	3
Carrier 7	3
Carrier 8	3
Carrier 9	12
Carrier 10	3

F.1.0.3. C7. Past Performance

The past performance criterion is meant to reflect the company's subjective opinion of a carrier, but based on past experiences. These past experiences however are based on objective data. It is based on whether a carrier is currently transporting the amount of volume that is awarded to that carrier. Important to note is that this information is currently only available from the Europe region. Besides, within this data, it is impossible to distinguish whether the under-performance is due to the company's disappointing volume or the carrier's under-performance. However, the company generally overestimates its volumes, which thus is reflected across all carriers.

To calculate the past performance, the weekly transported volume by a carrier is divided by the weekly nominated volume of a carrier. Hereafter, the sum of all the available weekly values is taken and divided by the number of weeks. A higher value is preferred as this indicates that a carrier is transporting more volume. Ten carriers have participated in the past tenders, but not all carriers are currently participating. For example, carrier 6 is currently not participating so no accurate volume data is available. Therefore, the average of all the carriers is taken and given to this carrier. The past performance of all carriers is presented in Table F.2 and is the same for all shipping lanes.

Table F.2: Past Performance

Carrier	Average awarded volume transported (%)
Carrier 1	25
Carrier 2	33
Carrier 3	14
Carrier 4	41
Carrier 5	14
Carrier 6	27
Carrier 7	8
Carrier 8	12
Carrier 9	75
Carrier 10	48

F.2. Social criteria

The social criteria are quantified using the sustainability reports of the carriers participating in the tender [67, 45, 17, 74, 75, 32, 110, 46, 112, 19]. The scores on the social criteria are given for the ten carriers currently participating in the tender. Important to note is that some reports contain numbers for 2023 and some only until 2022. From which year the values are used is indicated in the text at a criteria. The value for a social criterion per carrier remains the same for each shipping lane and will not change. This is because the values for the criteria are based on annual figures. These values may be adjusted based on the carrier's new annual sustainability reports. How each criterion is quantified and what value it gets for each carrier is further explained below. Finally, an overview of the values is presented in Table F.3.

F.2.0.1. C8. Work Safety

Work safety is quantified in the number of fatal accidents that occurred in the past year of a carrier. These numbers are directly reported in the sustainability report. To have the best comparison between the different carriers it is chosen to use the number of fatalities from the year 2022.

In the case of this criterion, a low value is preferred, as less fatal accidents are better. So by calculating the ideal best and ideal worst value the minimum available value is determined to be the best and the maximum available value to be the worst.

F.2.0.2. C9. Labour Health

This criterion is similar to the one above, yet slightly different. Moreover, this criterion is very difficult to measure. The Lost Time Injury Frequency Rate (LTIFR) was chosen. This gives the number of accidents with a million hours of exposure. In other words, a work-related injury that results in a person being unable to return to work and perform his or her duties within 24 hours of the injury is the number of lost time accidents per million exposure hours.

In some sustainability reports the value of LTIFR is given and in some it needs to be calculated by the following formula [2]:

$$\textbf{LTIFR} = \frac{\text{Number of lost time injuries in the reporting period} \times 1{,}000{,}000}{\text{Total hours worked in the reporting period}}$$

For carrier 4 no data is found so therefore it is chosen to give this carrier the same value as carrier 1 as it is assumed that these carriers are most alike. Furthermore, it is chosen to use all the values from the year 2022 to have a good comparison.

For this criterion, the same applies as the previous criterion: a lower value is preferred and thus seen as better. The same is therefore applied. The minimum value is the ideal best and the maximum value is the ideal worst.

F.2.0.3. C10. Respect for ethical issues and legal compliance

This criterion is quantified by the percentage of employees who completed the code of conduct training or the ethics and compliance issues training of a company. This information is reported in the sustainability reports. Important to note is that the most recently available value for each carrier is taken. For some carriers, the values from 2022 were used, while for others, values from 2023 were utilised. It is expected that this will not result in significantly different outcomes. Furthermore, a lower value for this criterion is preferred as that reflects more trained employees.

F.2.0.4. C11. Employee interests and rights

This criterion is quantified based on the percentage of employee relations and labour rights training targets achieved. A higher score on this criterion is preferred. This data is taken from the sustainability reports of the various carriers. Important to note, is that carrier 3 does not report any data on this, so the percentage of employees with access to primary health care is taken. In addition, some reports only contain the values for the year 2023. When this is the case these numbers are taken and otherwise the values from the year 2022. It is expected that this will not lead to very different outcomes.

Table F.3: Quantification of social criteria

Carrier	C8. Fatalities (#)	C9. LTIFR (#Incidents/Hour)	C10. Completed Code (%)	C11. Completed training (%)
Carrier 1	9	0.93	92	90
Carrier 2	0	1.13	93	86
Carrier 3	2	0.72	90	98
Carrier 4	4	0.93	80	80
Carrier 5	0	0.37	100	98.8
Carrier 6	0	1.47	89	89
Carrier 7	0	0.24	46.4	92
Carrier 8	0	0.77	96	96.1
Carrier 9	0	1.34	90	90
Carrier 10	0	0.00	96	100

F.3. Environmental criteria

The environmental criteria are quantified by also using the sustainability reports of the potential carriers participating in the tender [67, 45, 17, 74, 75, 32, 110, 46, 112, 19].

F.3.0.1. C12. CO_2 Emission per Shipment

This criterion focuses solely on the direct measurement of CO_2 emissions from the transportation of each shipment. The criterion is already quantified, tons of CO_2, but a higher value for this criterion is not desired. Meaning that a high value is not good and should not get a high weight. Therefore, in TOPSIS the minimum value is defined as the ideal best and the maximum value is defined as the ideal worst.

Furthermore, the carriers that offer a service for a specific shipping lane could indicate the amount of CO_2 that is emitted by shipping one container (TEU) over that specific shipping lane. Sometimes multiple options with different CO_2 amounts might be possible. If this is the case and there is no price difference then the average is taken. The CO_2 footprint is expressed using WTW (Well to Wake) analysis. WTW analysis assesses emissions from fuel production (well) to vessel propulsion (wake), encompassing the entire vessel life-cycle, including fuel extraction, production, transportation, and combustion. This helps stakeholders to understand maritime transportation's environmental impact and identify emission reduction opportunities. It is important to note that obtaining CO_2 emissions data for all carriers and shipping lanes in this study was not possible. For one carrier, this information was unavailable for any shipping lane, and for another carrier, it was missing for one specific shipping lane. In these instances, the average CO_2 emissions of all other carriers on the respective shipping lanes were utilised.

F.3.0.2. C13. Compliance with sustainability regulations

This criterion encompasses a broad range of regulatory compliance, including but not limited to CO_2 emissions, ensuring adherence to all environmental sustainability laws. It accounts for overall regulatory compliance, which may implicitly include CO_2 emissions, but also covers other environmental aspects. A higher score on this criterion is thus preferred.

Following IMO Regulation, the goal is to reduce emissions by at least 40% by 2030, compared to 2008. In addition, the use of technologies, fuels and/or energy sources with zero or near-zero greenhouse gas emissions should account for at least 5% by 2030 and 10% in the future of energy used by international shipping [70]. The most recently available data of each carrier have been used.

From the sustainability reports it becomes clear that all the shipping companies comply with the IMO regulation. Therefore it is chosen to use the percentage of how far a company is in reaching the goals compared to 2008 shown in Table F.4. This could indicate how good a company is on track with the future goals set by IMO. Furthermore, the values found for this criterion per shipping line will remain the same for each shipping lane. This is because these values do not depend on a shipping lane. Per year, these values could easily be adjusted to the updated values. In addition, the values are given for the currently participating carriers in the tender.

F.3.0.3. C14. Fuel Type

This criterion emphasises the environmental benefits of different types of fuel, considering factors like emissions of various pollutants, including but not limited to CO_2. *Fuel Type* is difficult to quantify because it is linked to other aspects. For example, the company may pay to sail a certain volume over a certain shipping lane with a certain percentage of alternative fuel. So the alternative fuel here is dependent on a certain volume, which is uncertain, but in addition to that comes additional costs.

Furthermore, there are several alternative fuels in circulation and not every alternative fuel is used by every shipping company. This makes it difficult to compare which is better. Therefore, it is chosen to use the Energy Efficiency Operating Indicator (EEOI) for now. EEOI assesses the energy efficiency of a vessel's operations, encompassing propulsion and movement across the water. Using alternative fuels with higher energy efficiency would lead to a reduced EEOI value. Consequently, if alternative fuels are used that result in lower CO_2 emissions than traditional fossil fuels, the EEOI would decrease. A lower value on this criterion is thus preferred. The EEOI of the different carriers is given in $gCO_2/TEUkm$.

In addition, the EEOI for the year 2022 is taken. The values are presented in Table F.4 for each carrier currently participating in the tender.

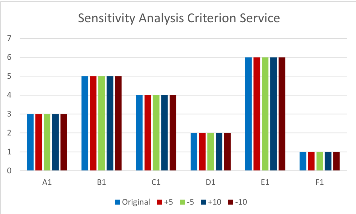
Table F.4: Quantification of environmental criteria

Carrier	C13. Proportion of target met (%)	C14. EEOI (gCO_2/TEUkm)
Carrier 1	39.9	24.1
Carrier 2	40.0	70.6
Carrier 3	50.0	61.4
Carrier 4	33.5	27.3
Carrier 5	58.5	41.6
Carrier 6	62.0	38.2
Carrier 7	59.5	40.2
Carrier 8	64.4	31.8
Carrier 9	33.0	83.0
Carrier 10	40.0	58.4

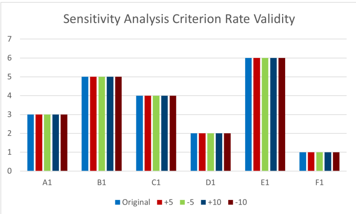
G
Percentage weight adjustment

In this appendix, the results of the percentage weight adjustment performed in subsection 5.6.2 are presented. From those Figures, it can be seen that no changes occurred except for shipping lane C. In Figure G.3 it can be seen that the number two and three carriers swap places when weights are adjusted for the criteria *Rate Validity* and *IMO Surcharge*.

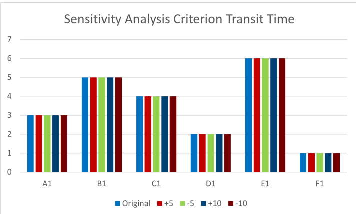
G.1. Percentage weight adjustment - Shipping lane A



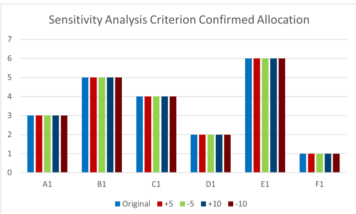
(a) Criterion Service



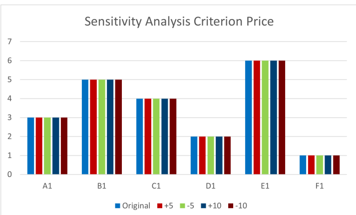
(b) Criterion Rate Validity



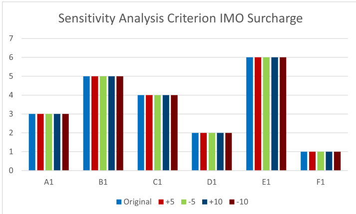
(c) Criterion Transit-time



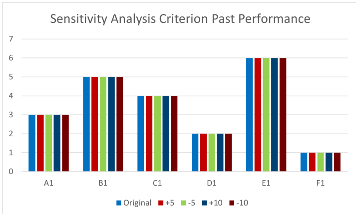
(d) Criterion Confirmed Allocation



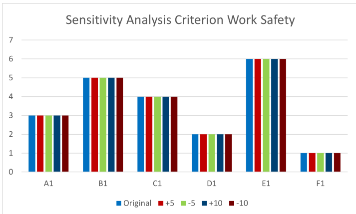
(e) Criterion Price



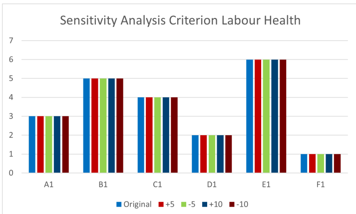
(f) Criterion IMO Surcharge



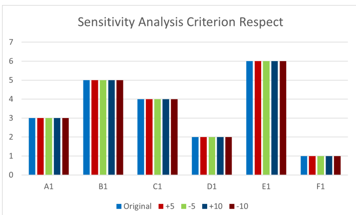
(g) Criterion Past Performance



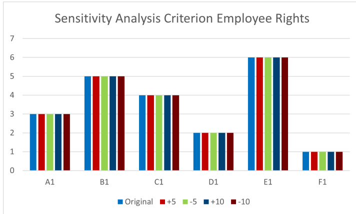
(h) Criterion Work Safety



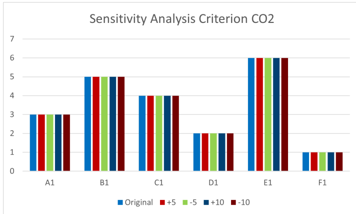
(i) Criterion Labour Health



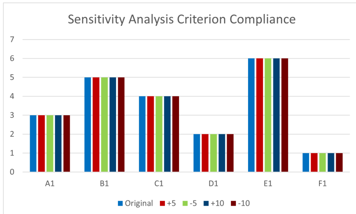
(j) Criterion Respect for ethical issues



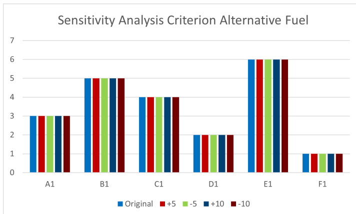
(k) Criterion Employee Rights



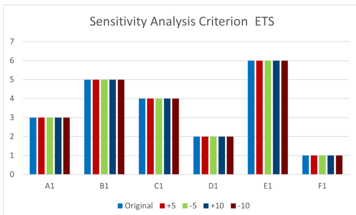
(l) Criterion CO_2



(m) Criterion Compliance with regulations



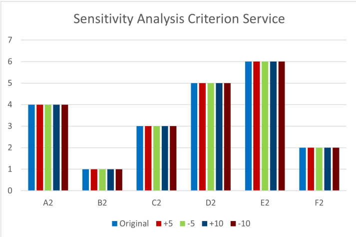
(n) Criterion Alternative Fuel



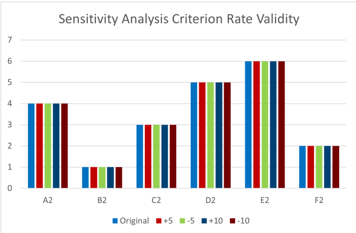
(o) Criterion ETS Fee

Figure G.1: Percentage weight adjustment - Shipping lane A

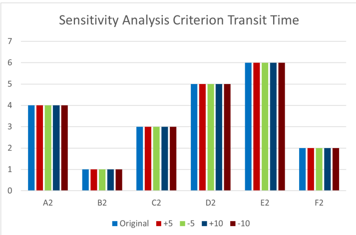
G.2. Percentage weight adjustment - Shipping lane B



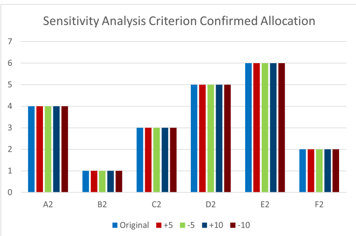
(a) Criterion Service



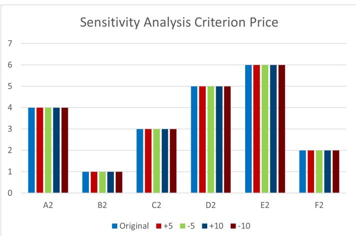
(b) Criterion Rate Validity



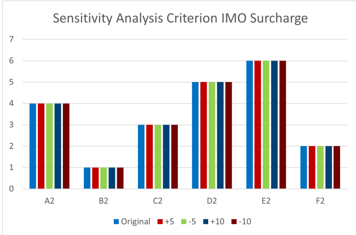
(c) Criterion Transit-time



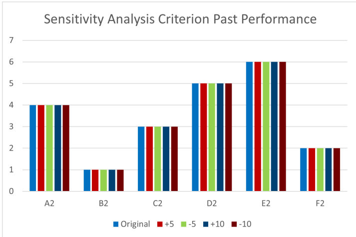
(d) Criterion Confirmed Allocation



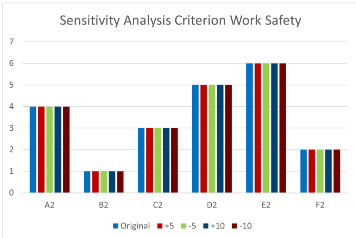
(e) Criterion Price



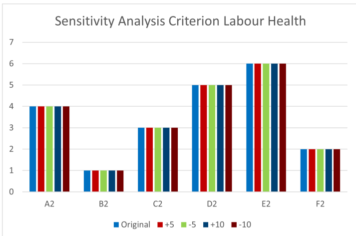
(f) Criterion IMO Surcharge



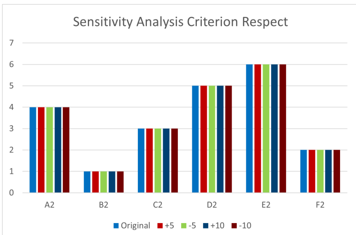
(g) Criterion Past Performance



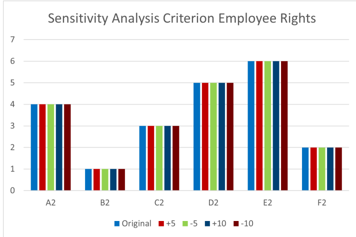
(h) Criterion Work Safety



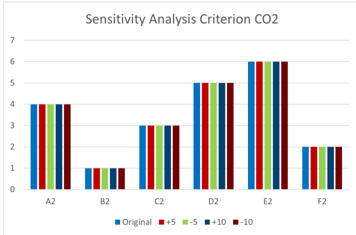
(i) Criterion Labour Health



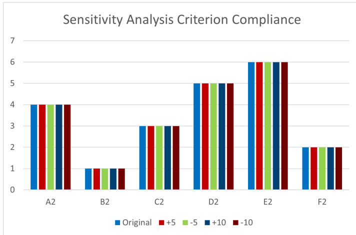
(j) Criterion Respect for ethical issues



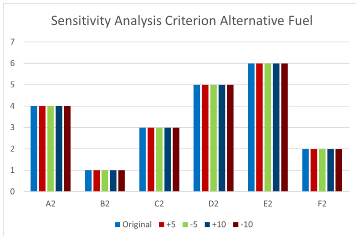
(k) Criterion Employee Rights



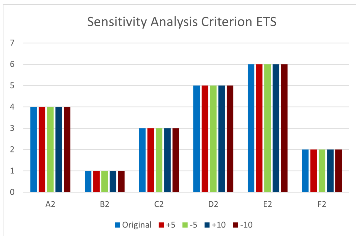
(l) Criterion CO_2



(m) Criterion Compliance with regulations



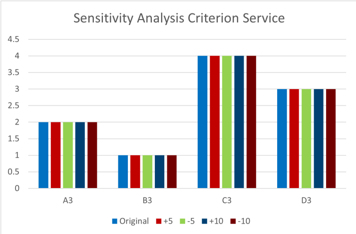
(n) Criterion Alternative Fuel



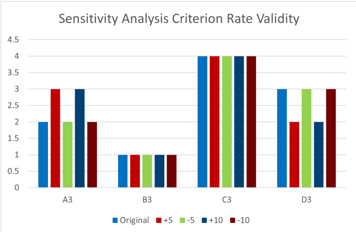
(o) Criterion ETS Fee

Figure G.2: Percentage weight adjustment - Shipping lane B

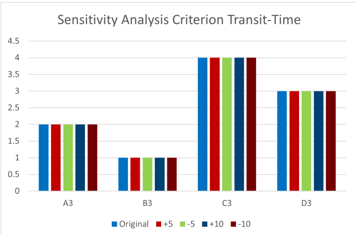
G.3. Percentage weight adjustment - Shipping lane C



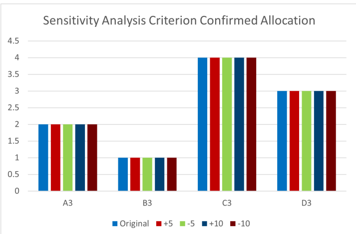
(a) Criterion Service



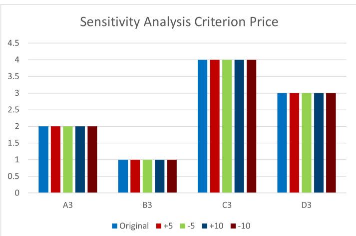
(b) Criterion Rate Validity



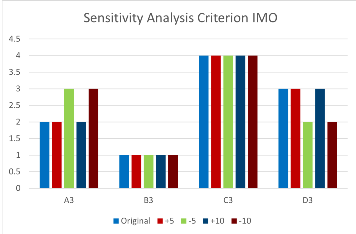
(c) Criterion Transit-time



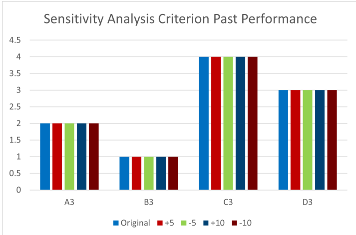
(d) Criterion Confirmed Allocation



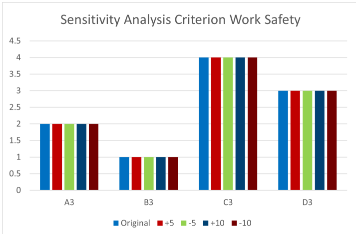
(e) Criterion Price



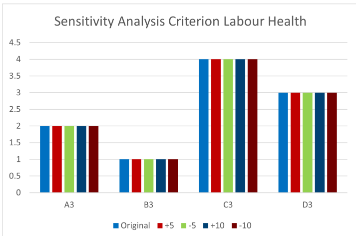
(f) Criterion IMO Surcharge



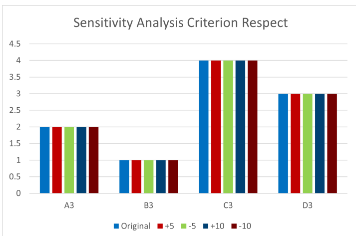
(g) Criterion Past Performance



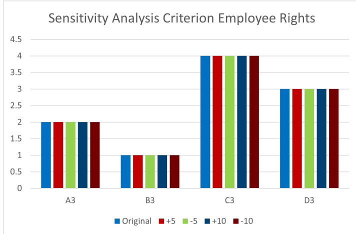
(h) Criterion Work Safety



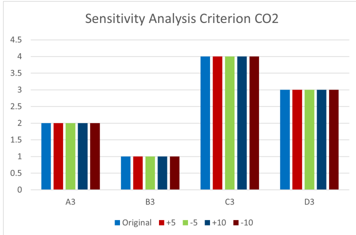
(i) Criterion Labour Health



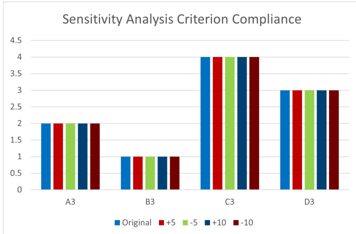
(j) Criterion Respect for ethical issues



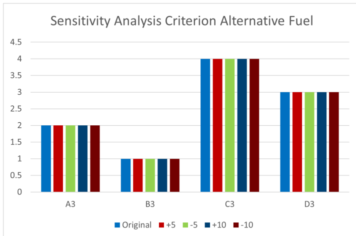
(k) Criterion Employee Rights



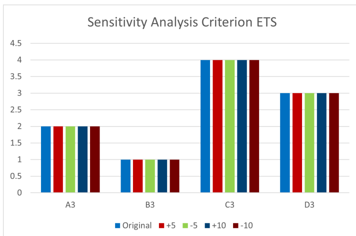
(l) Criterion CO_2



(m) Criterion Compliance with regulations



(n) Criterion Alternative Fuel



(o) Criterion ETS Fee

Figure G.3: Percentage weight adjustment - Shipping lane C