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Selecting carriers for overseas tank container transport with sustainability objectives

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Abstract – The logistics industry is increasingly prioritizing sustainability, requiring a comprehensive approach to carrier selection for transporting tank containers overseas. Current studies often focus only on economic factors, but social and environmental aspects are also crucial for sustainable logistics practices. This research introduces a Multi-Criteria Decision-Making (MCDM) framework combining the Best-Worst Method (BWM) and Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS). Through a literature review, expert interviews, and secondary data analysis, relevant criteria are identified. The framework is applied to a case study to evaluate carriers for overseas tank container transport on three major shipping lanes, incorporating sustainability objectives alongside traditional criteria. The results show a balanced and clear carrier selection process aligning with current sustainability goals. The findings highlight the possibility of including sustainability criteria without significant costs, providing practical recommendations for logistics companies to improve their carrier selection practices and support long-term environmental and social benefits.

Keywords: Carrier selection; MCDM; BWM; TOPSIS; Sustainability; Tank container

1. Introduction

Maritime transport plays a pivotal role in global trade, with over 80% of the world's goods being transported by sea (International Tank Container Organization, 2023). Tank container transport has emerged as a significant component within this domain, experiencing notable growth in recent years. The expansion of the global tank container fleet underscores the dynamics of this sector, with the global fleet expanding by 8.65% in 2022, surpassing the 7.3% growth of 2021 (United Nations Conference on Trade and Development, 2021). However, container transport in logistics comes with its challenges. Various factors influence container logistics, including fluctuating demand, new routes, port developments, route blockages, and the need for larger vessels (Fan et al., 2015).

These days, companies face intense pressure to reduce costs and maintain competitiveness. Carrier selection emerges as a crucial element of operational efficiency and competitiveness for logistics companies. Effective carrier selection is important for business operations and competitiveness, as it directly impacts organizational performance (Chan & Kumar, 2007). Selecting carriers that provide high-quality services at competitive rates and reliable transit times is essential for logistics companies (Ergin et al., 2022). However, this process is challenging due to ongoing uncertainty and complexity, particularly for specialized carriers in global supply chains (Ergin & Alkan, 2023). Carrier selection is a critical procurement decision within logistics, extensively covered in the literature (Brooks, 1990; Ergin & Alkan, 2023; Ergin et al., 2022; Gailus & Jahn, 2015; Lin & Yeh, 2010, 2013; Mohammaditabar & Teimoury, 2008; Wong et al., 2008). Typically, multiple carriers operate on each route, connecting two locations within the logistics network. Selecting carriers involves choosing a single carrier for

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transporting freight along a specific route (Lin & Yeh, 2010, 2013). Besides, transportation has a significant environmental impact, contributing greatly to Europe's greenhouse gas emissions (Gustafsson et al., 2021; Wolf & Seuring, 2010). Therefore, there is a growing demand to address sustainability in carrier selection (Meixell & Norbis, 2008; Williams et al., 2013). As Thomas et al. (2016) suggest, adopting sustainable practices allows organizations to differentiate themselves competitively.

The primary 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) for determining the weights of criteria and the Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS) for the final evaluation and ranking of the carriers, with a focus on incorporating sustainability objectives. A case study is used to systematically gain a better understanding of carrier selection, also drawing on literature review, expert insights, and secondary data analysis. The case company operates as a freight forwarder, not a producer or user, and plays a crucial role in the logistics network. They act as a link in the supply chain, ensuring the efficient movement of goods. The requirements for their carriers are driven not only by their own need for profitability and sustainability goals but also by the demands of the company's customers, who have their own specific requirements in these areas.

The study aims to comprehensively understand carrier selection processes in logistics. Ultimately, the research aims to provide actionable insights and recommendations to improve carrier selection for transporting tank containers overseas, contributing to more sustainable logistics practices in global trade.

2. Literature review

This section presents a comprehensive review of the literature on carrier selection in logistics, highlighting current research on criteria and the inclusion of sustainability.

2.1 Carrier selection

While there is existing research on carrier selection, studies specifically focused on selecting carriers for transporting tank containers overseas are limited. Besides, the existing research on ocean carrier selection is limited and is often region-specific. For instance, Brooks (1995) explored North Atlantic shipping, while studies by Tiwari et al. (2003) and Wong et al. (2008) focused on Chinese shippers, and Shang and Lu (2012) examined Taiwan. Studies in Thailand (Banomyong & Supatn, 2011; Setamanit & Pipatwattana, 2015), India (Kannan et al., 2010), and Ghana (Fanam et al., 2016) further highlight the geographical variance in carrier selection factors. 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 (2008) suggests that geographic location influences carrier selection.

Furthermore, research on carrier selection typically focuses on identifying selection criteria using surveys and questionnaires, useful for carriers to adjust strategies to attract shippers (Brooks, 1990; Fanam & Ackerly, 2019; Kannan et al., 2010; Mohammaditabar & Teimoury, 2008; Fanam et al., 2016; Setamanit & Pipatwattana, 2015; Wong et al., 2008). Recent studies by Ergin et al. (2022) and Ergin and Alkan (2023) provide insights into evolving criteria and new MCDM methods for ocean carrier selection, emphasizing the need for regional comparisons and broader applications beyond container transportation. In addition, several studies try to enhance the understanding of carrier selection in logistics. Lin and Yeh (2010) focuses on network reliability for carrier selection from Asia to Europe, uncovering various possibilities for optimizing routes. Additionally, Gailus and Jahn (2015) identify 20 decision paths for container carrier selection, offering valuable insights into the tender process.

In summary, while much research covers carrier selection criteria, there is a gap in understanding the decision-making process and criteria impact. Studies on ocean carrier selection are limited and region-specific. Additionally, research often neglects tank containers and their overseas transport, indicating a need for further study.

2.2 Criteria for Carrier Selection

Extensive research has focused on carrier selection criteria. From 1984 to 2016, Ergin et al. (2022) identified 32 criteria summarized in Table 1. For freight forwarders, the top five criteria are equipment availability (C27), low freight costs (C1), on-time release of the bill of lading (C13), confidentiality (C25), and service schedule reliability (C16). The least important criteria include inland cost (C4), credit facility (C2), quality certification (C24), sales call regularity (C9), and demurrage and detention tariff (C3). 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 1. Known criteria for carrier selection

Criterion	Source
1. Low freight	(Brooks, 1990), (Brooks, 1995), (Collison, 1984), (Kent & Parker, 1999)
2. Credit facility	(Collison, 1984), (Kent & Parker, 1999)
3. Demurrage and detention tariff	(Wong et al., 2008)
4. Inland cost	(Collison, 1984), (Brooks, 1990)
5. Assigned customer representative	(Parasuraman et al., 1988)
6. Customer communication management	(Brooks, 1990) , (Wen & Huang, 2007)
7. On-time notification of the customer	(Brooks, 1995) , (Wen & Huang, 2007)
8. Employee competence	(Kent & Parker, 1999), (Lu, 2003)
9. Sales call regularity	(Brooks, 1990) , (Lu, 2003)
10. Cargo damaged and claim settlement process management	(Brooks, 1990) , (Kent & Parker,1999)
11. Cargo safety	(Brooks, 1990) , (Lu, 2003)
12. Documentation quality and accurate invoicing	(Kannan et al., 2012)
13. On-time release of bill of lading	(Brooks, 1990) , (Lu, 2003)
14. Direct shipping to destination port	(Collison, 1984), (Lu, 2003)
15. Transit time	(Lu, 2003), (Wen & Huang, 2007
16. Service schedule reliability	(Lu, 2003), (Wong et al., 2008)
17. Vessel capacity and easiness of booking	(Collison, 1984), (Brooks, 1990)
18. Geographical coverage	(Collison, 1984), (Kent & Parker, 1999)
19. Serves frequency	(Collison, 1984), (Brooks, 1990)
20. Container demurrage free time and detention free days	(Lu, 2003), (Kannan et al., 2012)
21. Carrier reputation	(Brooks, 1995) , (Lu, 2003)
22. Carrier financial stability	(Kannan et al., 2012)
23. Professional appearance of sales personnel	(Brooks, 1990) , (Wen & Lin, 2016)
24. Quality certification	(Collison, 1984), (Lu, 2003)
25. Confidentiality	(Lu, 2003), (Wen & Huang, 2007)
26. Safety of life at sea and marine pollution prevention policy	(Lu, 2003), (Wong et al., 2008)
27. Equipment availability	(Collison, 1984), (Brooks, 1995)
28. Condition of container	(Collison, 1984), (Brooks, 1995)
29. Special equipment availability	(Collison, 1984), (Kent & Parker,1999)
30. Container tracking system	(Collison, 1984), (Brooks, 1990)
31. Online reservation	(Kannan et al., 2011), (Kannan et al., 2012)
32. Electronic data interchange	(Lu, 2003), (Wen & Lin, 2016)

2.3 Sustainable Carrier Selection

As mentioned in the introduction, there is a growing demand to address sustainability in carrier selection. Sustainability is a multidimensional concept encompassing economic, social, and environmental dimensions (Busco et al., 2013; Teodorescu, 2015). Economically, it involves financial viability and optimal resource utilization. Socially, it focuses on equitable communities and improving quality of life. Environmentally, it addresses resource management, biodiversity conservation, and climate change mitigation. This framework supports sustainable development by balancing economic, social, and environmental factors. Traditionally, sustainability has not been a primary consideration when selecting carriers, with the economic dimension being the dominant factor (Meixell & Norbis, 2008; Williams et al., 2013). Reviews of carrier selection studies indicate that sustainability has been a missing theme (Meixell & Norbis, 2008; Williams et al., 2013). Researchers are actively exploring how companies can incorporate sustainable criteria into the carrier selection process. Bask et al. (2016) found that while environmental sustainability functions as an order qualifier, it is not typically an order winner. Carriers struggle to differentiate based solely on environmental criteria, but combining sustainability with operational efficiency can be cost-effective. Environmentally proactive logistics providers often outperform others financially. Furthermore, Davis-Sramek et al. (2020) examined the influence of carriers' environmental and social performance on shippers' decisions and trust. The study highlights the long-term impact of environmental factors and the short-term significance of social factors in carrier selection. Ergin and Alkan (2023) promote more environmental criteria in ocean carrier selection, while Rosano et al. (2022) call for analyzing the interests of logistics operators in environmentally friendly practices.

2.4 Conclusion and discussion literature review

The literature review highlights the gap in research on the carrier selection process, especially for ocean container carriers, including tank containers. Key criteria for carrier selection include equipment availability, low freight costs, timely release of waybills, confidentiality, and service schedule reliability. The lack of focus on sustainability criteria suggests a need for future research. Sustainability, covering economic, societal, and environmental aspects, is essential due to the environmental impact of transportation. More research is needed to integrate sustainability into carrier selection. The identified knowledge gaps have significant implications for logistics and transportation, particularly in response to environmental issues. As sustainability becomes crucial, the lack of focus on integrating sustainability criteria into carrier selection requires further research. Addressing this gap can improve sustainable carrier selection in overseas tank container transport.

3. Methodology

To understand carrier selection and identify criteria, key stakeholders are interviewed individually to avoid external influence, following Hancock (2007). Secondary data analysis offers insights into the current process and requirements (Ruggiano & Perry, 2019). Additionally, a literature review identifies relevant criteria, and MCDM methods are explained in the following sections.

3.1 Multi-criteria decision-making (MCDM)

Multiple methods have been used to study carrier selection, with MCDM being frequently utilized (Bagchi, 1989; Ergin et al., 2022; Mohammaditabar & Teimoury, 2008; Tubis & Werbinska-Wojciechowska, 2023; Wong et al., 2008). MCDM is preferred over methods like Cost-Benefit Analysis (CBA) because some criteria in carrier selection cannot be expressed in monetary terms. Additionally, literature lacks comparisons of multiple MCDM approaches for carrier selection, with most studies applying a single method and with AHP being more common in ocean carrier selection (Bagchi, 1989; Ergin & Alkan, 2023; Ergin et al., 2022; Mohammaditabar & Teimoury, 2008; Fanam et al., 2016; Sahin et al., 2020; Tubis & Werbinska-Wojciechowska, 2023; Wong et al., 2008). While various studies provide overviews of MCDM selection models, they often focus on specific periods (Chai et al., 2013; De Boer et al., 2001; Ho et al., 2010; Weber et al., 1991). For instance, Dewayana et al. (2023) cover methods from 2013 to 2020, introducing the Best-Worst Method (BWM).

3.1.1 Best-Worst Method (BWM)

The Best-Worst Method (BWM), developed in 2015, is chosen for determining the weights of the criteria due to its advantages over traditional methods like AHP, which is frequently used in MCDM studies (Chai et al., 2013; Ho et al., 2010). BWM addresses MCDM problems through pairwise comparisons of the best and worst criteria, requiring fewer comparisons and offering reliable and consistent weights (Gupta et al., 2021; Malek & Desai, 2019; Rezaei, 2015). It uses a systematic approach to reduce subjectivity and bias, and its straightforward process allows for broad participation, even from those without advanced expertise (Rezaei, 2015). Studies show BWM's superiority in statistical validation and consistency over AHP (Gupta et al., 2021; Liu et al., 2021; Moslem et al., 2020), as well as its minimal data requirements and time efficiency (Wankhede & Vinodh, 2021).

Despite being relatively new, BWM has been widely applied across various industries. Although widely applied in various industries, BWM has not yet been specifically applied to overseas tank container transport (Gidiagba et al., 2023; Liu et al., 2019; Lo et al., 2018; Rezaei et al., 2016; Sulistyoningarum et al., 2019; Tatlıcı Kupeli & Sertyesilisik, 2023; Ulutas, 2021; Yucesan et al., 2019). Some studies have used BWM for carrier evaluation (Ding et al., 2023; Li et al., 2023; Rezaei et al., 2017, 2019; Tanrıverdi et al., 2022), but not specifically for selecting carriers. It is also frequently used for sustainable supplier selection, often in combination with other methods (Dewi & Zagloel, 2023; Karakoc et al., 2023). The following steps are required for BWM:

Step 1 - Determine set of decision criteria

The first step involves finding and determining the criteria $(c_1, c_2, \ldots, c_n)$ on which the decision should be based. This is done through interviews, secondary data analyses and literature review. The performance of the carriers is 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. This results in the following Best-to-Others vector: $A_B = (a_{B1}, a_{B2}, \ldots . a_{Bn})$ 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. This results in the following Others-to-Worst vector: $A_W = (a_{1W}, a_{2W}, \ldots . a_{nW})^T$ 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 last step is to determine the optimal weights $W = w_1, w_2, \dots, w_n$. 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 minimized, which is translated to the following min-max model:

$$\min max_j \{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W|\} \quad (1)$$
$$\text{s.t.}$$
$$\sum_j w_j = 1$$
$$w_j \geq 0, for\ all\ j$$

Model 1 can be equated to the minimum value of ξ^L to calculate optimal criteria weights, so that:

$$\min \xi^L \quad (2)$$
$$\text{s.t.}$$
$$|w_B - a_{Bj}w_j| \leq \xi^L, for\ all\ j$$
$$|w_j - a_{jW}w_W| \leq \xi^L, for\ all\ j$$
$$\sum_j w_j = 1$$
$$w_j \geq 0, for\ all\ j$$

By solving the second model the optimal weights $(w_1, w_2, \dots, w_n)$ and the 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 not, the comparisons may need to be reviewed and adjusted (Rezaei, 2016).

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

To apply TOPSIS, carriers need to be sourced along with their scores on the selected criteria. Once the criteria, their weights, the carriers, and the carriers' scores are known, TOPSIS can be applied. TOPSIS is often used with BWM in MCDM analysis (Gidiagba et al., 2023; Lo et al., 2018; Yucesan et al., 2019). It evaluates alternatives based on their Euclidean distance to ideal and non-ideal solutions, allowing for nuanced assessments and effective trade-offs, crucial for complex decisions like carrier selection. Unlike non-compensatory methods, TOPSIS captures interactions between criteria and uses normalization and aggregation for fair comparisons. However, TOPSIS can be sensitive to assigned weights and linearity assumptions. The following steps must be taken for TOPSIS.

Step 1 - Create performance matrix

Construct a performance matrix $(z_{ij})_{mxn}$ as shown in Table 2. Before creating the performance matrix the criteria, the criteria weights and the carriers (alternatives) should be known. Scores are assigned for each carrier-criterion combination, and each criterion is thus weighted by BWM (Garcıa-Cascales & Lamata, 2012). 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. The performance matrix provides a structured framework for assessing carriers based on sustainability criteria, supporting quantifiable and transparent evaluations. This matrix aids communication and understanding, ensuring the reliability of assessments and accommodating evolving circumstances.

Table 2. Performance matrix

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

Step 2 - Normalize the performance matrix

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

$$r_{ij} = \frac{z_{ij}}{\sqrt{\sum_{k=1}^{m} z_{kj}^2}} \ , i = 1,2, \dots, m, \quad j = 1,2, \dots, n \tag{3}$$

Step 3 - Calculate the weighted normalized decision matrix

In this step, the weighted normalized decision matrix is calculated. This is done as follows:

$$t_{ij} = r_{ij} \cdot w_j \ , \qquad i = 1,2, \dots, m, \quad j = 1,2, \dots, n \tag{4}$$

where

$$w_j = \frac{W_j}{\sum_{k=1}^{n} W_k} \ , \qquad j = 1,2, \dots, n \tag{5}$$

so that

$$\sum_{i=1}^{m} w_i = 1 \tag{6}$$

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:

$$Carrier_w = \{\langle max\,(t_{ij}\,|i = 1,2,\dots,m|\,j \in J_-)\rangle, \langle min\,(t_{ij}\,|i = 1,2,\dots,m|\,j \in J_+)\rangle\} \equiv \{t_{wj}\,|j = 1,2,\dots,n|\},$$

$$Carrier_b = \{\langle min\,(t_{ij}\,|i = 1,2,\dots,m|\,j \in J_-)\rangle, \langle max\,(t_{ij}\,|i = 1,2,\dots,m|\,j \in J_+)\rangle\} \equiv \{t_{bj}\,|j = 1,2,\dots,n|\}, \quad (7)$$

where

$J_+ = \{j = 1,2,\dots,n \mid j\}$ associated with the criteria having a positive impact, and

$J_- = \{j = 1,2,\dots,n \mid j\}$ associated with the criteria having a negative impact.

(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:

$$d_{iw} = \sqrt{\sum_{j=1}^{n}(t_{ij} - t_{wj})^2}\,,\ i = 1,2,\dots,m \quad (9)$$

And the distance between the alternative t_i and the best condition t_b:

$$d_{ib} = \sqrt{\sum_{j=1}^{n}(t_{ij} - t_{bj})^2}\,,\ i = 1,2,\dots,m \quad (10)$$

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:

$$s_{iw} = \frac{d_{iw}}{d_{iw} + d_{ib}}\,, 0 \le s_{iw} \le 1, \qquad i = 1,2,\dots,m \quad (11)$$

$s_{iw} = 1$ 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, the carriers are evaluated according to s_{iw} $(i = 1,2,\dots,m)$.

4. Case Study

The case study contributes to a deeper understanding of the carrier selection process in the logistics industry, providing valuable insights for future research and practical applications in similar contexts. The case company, a global logistics business operating as a freight forwarder, is recognized for its extensive experience in transporting tank containers, ensuring the safe and efficient delivery of various types of liquid products. However, the company faces challenges in selecting carriers for the transport of tank containers overseas, partly due to current issues in the Red Sea. Additionally, the requirements for their carriers are driven not only by the company's own need for profitability and sustainability goals but also by the demands of their customers, who have their own specific requirements in these areas. Therefore, the methodologies outlined in Section 3 are applied to the company to improve their carrier selection process. Within the company, there are three primary decision-makers involved in the carrier selection process, each playing an equally important role. Although they are equally important, they may prioritize factors differently. Thus, they are considered as three individuals in this research. This is crucial when determining the weights of the criteria.

The company utilizes a range of carriers to transport tank containers over multiple shipping lanes. For most shipping lanes, there are three to six carriers that offer a service across that shipping lane. Furthermore, there are three major shipping lanes, designated as A, B, and C, which have been used regularly over the years. The company makes use of a tender process to select its carriers. This ensures transparency, competitiveness, and the best possible service. During this process, carriers are being evaluated based on four criteria: service, transit time, confirmed allocation, and price to which no specific weight is given. Additionally, the company implicitly uses the theory of lexicographic ordering for evaluating the carriers, with price being the most important criterion (Encarnacion, 1964; Georgescu-Roegen, 1954). This non-compensatory decision-making approach evaluates alternatives based on one criterion at a time, starting with the most important one. If alternatives are identical based on the first criterion, the next criterion is considered, and this process continues until a difference is found. This method ensures that the decision is based on the most critical factor first, reflecting a structured and hierarchical approach to carrier selection (Simsek, 2020). Furthermore, factors like carrier experience and reliability, though not explicitly mentioned by the company, influence the final decision.

5. Results

This section presents the criteria and their weights. Additionally, the sourced carriers and performance matrices are presented. Hereafter, the results of applying TOPSIS are outlined. Finally, sensitivity analyses, verification and validation are discussed.

5.1 Identified and selected criteria

A comprehensive literature review and interviews identified numerous decision criteria across economic, social, and environmental categories of sustainability. Initially, 34 criteria are found and categorized. To make the list practical for BWM, the three key decision-makers helped in further reducing the list by filling in a survey and indicating for each of the 34 criteria whether a criterion should be included, maybe included or not included when selecting a carrier. This resulted in 15 criteria, which are presented in Table 3 with their corresponding units. For TOPSIS the preferred direction of a criterion is needed. This is reflected in the "Dir." column. A + indicates that a higher value is preferred and a - indicates that a lower value is preferred.

5.2 Criteria weights

With the decision criteria established, weights are assigned using BWM. After this, the weights found with BWM are aggregated to determine the final weights.

5.2.1 BWM

To determine the weights of these criteria with BWM a level of hierarchy is added as there are more than nine criteria (Rezaei, 2015). Therefore, four analyses are conducted per decision-maker: the categories, economic criteria, social criteria and environmental criteria. Each analysis requires two sets of pairwise comparisons (PC) to be performed by each decision-maker. This results in multiple weights for each analysis as can be seen in Figure 1.

For reliability reasons, the consistency ratios (CR) of all the pairwise comparison analyses have to be checked. The CR and the corresponding thresholds are presented in Table 4, and they are all accepted. From Figure 1a, it can be seen that all three decision-makers assign nearly identical weights to each category. Overall, there is a consensus that the economic category is the most important. While all three decision-makers similarly weigh social criteria, DM3 gives more importance to the ETS fee among environmental criteria as can be seen in Figure 1b. Price is most important to all, but DM1 values past performance, DM2 emphasizes rate validity, and DM3 highlights transit-time. These small differences suggest that having a single decision-maker in the future could slightly alter the results.

Table 3. Selected list of criteria

Cat.	Criterion	Description	Unit	Dir.
Economic	**C1:**Service	The number of ports of call a carrier uses to transport a tank container.	Ports of call (#)	-
	C2: Rate validity	The period for which the agreed rates are valid.	Months (#)	+
	C3: Transit-time	The time needed to move goods from origin to destination.	Days (#)	-
	C4: Confirmed allocation	The guaranteed space for cargo on the transport vessel.	TEU (#)	+
	C5: Price	The cost of the transport service.	Dollar ($)	-
	C6: IMO surcharge	The extra fee imposed by carriers for transporting goods classified as dangerous by the International Maritime Organization.	Dollar ($)	-
	C7: Past performance	The amount of volume a carrier is currently transporting compared to the awarded volume to that carrier.	Average awarded volume transported (%)	+
Social	**C8:**Work Safety	Prevention of workplace accidents and ensuring a secure work environment through safety protocols, equipment, and training.	Fatalities (#)	-
	C9: Labour Health	The well-being of employees, encompassing physical and mental aspects.	LTIFR (#Incidents/ Hour)	-
	C10: Respect for ethical issues and legal compliance	The commitment of a carrier to moral principles and adherence to laws and regulations.	Completed Code (%)	+
	C11: Employee interests and rights	Consideration for the rights and interests of employees.	Completed training (%)	+
Environmental	**C12:**CO2 Emission per Shipment	The amount of carbon dioxide emitted during transportation.	CO2 (tons)	-
	C13: Compliance with sustainability regulations	Adherence to environmental sustainability laws and regulations.	Proportion of target met (%)	+
	C14: Fuel Type	The type of fuel used by the transport.	EEOI (gCO2/TEUkm)	-
	C15:ETS Fee	A charge imposed by carriers to comply with the Emissions Trading Systems (ETS), aiming to reduce greenhouse gas emissions.	Dollar ($)	-

Table 4. Consistency ratios and thresholds

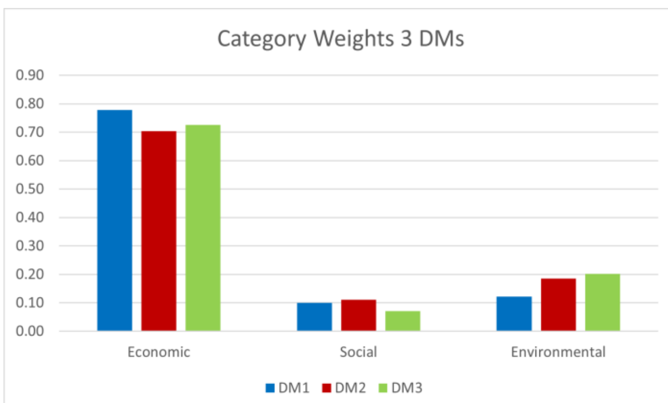
PC Analysis 1	PC Analysis 2	PC Analysis 3	PC Analysis 4

	CR	Threshold	CR	Threshold	CR	Threshold	CR	Threshold
1	0.107	0.131	0.292	0.352	0.000	0.000	0.000	0.000
2	0.067	0.133	0.071	0.341	0.000	0.000	0.000	0.000
3	0.097	0.136	0.319	0.352	0.000	0.000	0.214	0.246

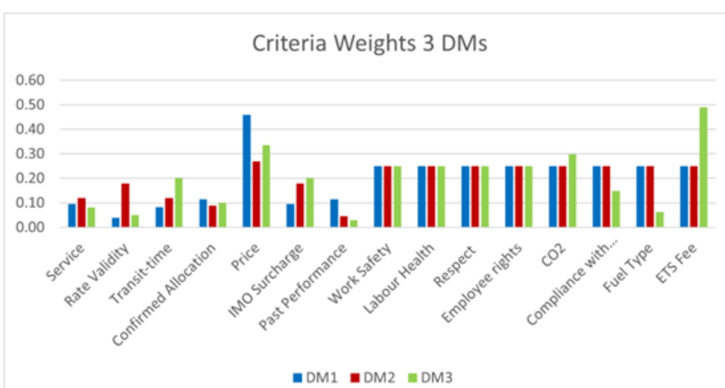
5.2.2 Final criteria weights

The geometric mean method is used to aggregate the weights into a single weight per category and criterion (Mikkonen et al., 2018). This method is particularly suitable for small decision-making groups due to its simplicity and robustness (Rezaei et al., 2023). To determine the final weights, each criterion weight is multiplied by its corresponding category weight, resulting in a single weight for each criterion. The final criteria weights are presented in Figure 2.

From Figure 2, it is evident that economic criteria are significantly more important than social and environmental criteria, as expected due to their higher assigned category weight. Environmental criteria are prioritized over social criteria because the company assumes carriers already meet high social standards. Price is identified as the most important criterion, followed by IMO surcharge and transit time, with all economic criteria outweighing social and environmental ones. Among environmental criteria, CO2 emission per shipment and ETS fee are the most crucial. Price is significantly more important, being 1.5 to 2 times more important than other economic criteria, almost 5 times more important than social criteria, and 2 to 5 times more important than environmental criteria like fuel type.



(a) Category weights decision-makers



(b) Criteria weights decision-makers

Figure 1. Overview weights decision-makers

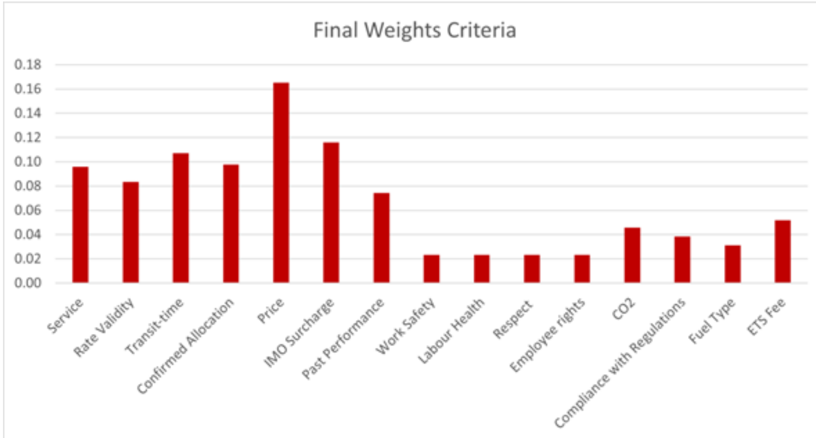


Figure 2. Final criteria weights

5.3 Sourced carriers

In parallel with BWM, carriers are sourced for evaluation on three key shipping lanes (A, B, and C) due to their significance and the number of available carriers. Some criteria require quantification, ensuring values adhere to interval or ratio scales. Quantified criteria include service efficiency, past performance, work safety, ethical compliance, CO_2 emissions, and sustainability compliance. An overview of the quantification of the criteria and their corresponding units is presented in Table 3.

5.4 Performance matrices

Performance matrices for the three shipping lanes are created using real input data from carriers. For instance, the criterion Past Performance (C7) is based on the carriers' current performance. The performance matrices for the three shipping lanes are presented below.

Table 5. 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

Table 6. 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

Table 7. 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

For applying TOPSIS to all three shipping lanes, all performance matrices are normalized and following this, the weighted normalized performance matrices are created. 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. Final performance scores and evaluations are presented for each shipping lane. Additionally, a cost comparison is given, assuming 100 TEUs are shipped. Decision-makers typically select two carriers for one shipping lane to spread their volumes and mitigate risk. The top carrier is assigned 80 TEUs (80%), while the second carrier transports 20 TEUs (20%), as detailed by the decision-makers. Total costs include price, IMO surcharge, and ETS fee. The overall cost is calculated by combining costs for the top two carriers. The results of the ship- ping lanes evaluations are presented in Table 8. Table 9 reflects the cost differences for all the shipping lanes. In both Tables, I represent the TOPSIS evaluation and II the company evaluation based on their last tender. The results for shipping lane A are discussed as an example, where Carrier E1 consistently ranks lowest in both evaluations, indicating consensus on its poor performance. Carriers B1 and C1 score similar in both evaluations, showing consistent relative performance. Carrier A1, ranked third by TOPSIS and second by the company, suggests a preference influenced by its lower price. Carrier F1, the top scorer in TOPSIS, is ranked fourth by the company, indicating consideration of additional factors. Evaluation discrepancies, especially for the top carrier, arise from differing criteria. The company's lexicographic ordering, which prioritizes price, makes D1 the top choice due to its low cost, affecting other evaluations. TOPSIS ranks carrier F1 highest based on its good performance on multiple criteria, despite average pricing.

Table 8. Carrier performance for different shipping lanes

Shipping Lane A				**Shipping Lane B**				**Shipping Lane C**			
Car.	**Performance Score**	**I**	**II**	**Car.**	**Performance Score**	**I**	**II**	**Car.**	**Performance Score**	**I**	**II**
A1	0.429	3	2	**A2**	0.584	4	3	**A3**	0.521	2	3
B1	0.362	5	5	**B2**	0.671	1	1	**B3**	0.689	1	1
C1	0.391	4	3	**C2**	0.616	3	2	**C3**	0.337	4	4
D1	0.545	2	1	**D2**	0.464	5	5	**D3**	0.511	3	2
E1	0.266	6	6	**E2**	0.326	6	6				
F1	0.622	1	4	**F2**	0.656	2	4				

Overall, the performance scores of two carriers are generally very close to each other within the shipping lanes. However, the positions in evaluation where this happens differ. Besides, it can be concluded that the TOPSIS evaluations (I) closely match the company's evaluations (II), with mostly minor differences in one place. Larger differences occur in the two cases. However, these differences can be explained by the fact that TOPSIS includes the scores on all criteria, unlike the lexicographic ordering approach by the company. This allows carriers to score higher in the evaluation when performing well on other criteria. Additionally, in TOPSIS current carrier performance data is used, whereas the company evaluation relies on past performance, explaining some differences. Furthermore, the lowest-scoring carriers show minimal differences across evaluations, indicating consistency.

Table 9: Cost differences for different shipping lanes

TEU	Shipping Lane A			Shipping Lane B			Shipping Lane C		
	I	II	Dif.	I	II	Dif.	I	II	Dif.
100	$146,200	$110,580	$35,620	$43,240	$36,780	$6,460	$96,260	$95,720	$540
1	$1,462.0	$1,105.8	$356.2	$432.4	$367.8	$64.6	$962.6	$957.2	$5.4

However, the inclusion of sustainability criteria entails additional costs, ranging from $5 to $350 per TEU, equating to 0.56% to 25% of total costs. Choosing a more sustain- able approach can thus be relatively inexpensive if the additional costs are minimal. While these additional costs are generally expected due to the different weighting of criteria within TOPSIS, they confirm that a more sustainable approach involves additional expenses. Lastly, the criterion for confirmed allocation (C4) shows no variation across evaluations, but it remains essential for future use due to potential carrier performance changes. This criterion ensures the robustness of the TOPSIS analysis, despite identical scores not affecting overall evaluation variability.

5.6 Sensitivity analyses

The effectiveness of BWM and TOPSIS is evaluated through percentage weight adjustments and scenario analyses. Furthermore, verification and validation are performed. The percentage weight adjustments tested the stability of the BWM weights and TOPSIS evaluations by varying the weights of each criterion by ±5% and ±10%. The results show that for shipping lanes A and B, the evaluations of carriers remain stable. For shipping lane C, a minor change in evaluation occurs, only when the weights of specific criteria are adjusted, suggesting that the evaluation remains consistent and is not sensitive to change. From this, it can be concluded that the chosen criteria and weights are robust and reliable.

In addition, three scenario analyses are performed to explore the impact of different weightings on the shipping lanes. Firstly, equal weighting of economic, social, and environmental criteria significantly changes carrier evaluations, favoring those carriers with strong social and environmental performance. Secondly, changing economic criteria, such as price and IMO surcharges, shows that small changes can reorder carriers, highlighting the importance of these criteria. Thirdly, changing the weight of economic or environmental categories shows that even small adjustments impact evaluations, with reducing the economic category’s weight having a more significant effect. This highlights the need for balanced performance across categories.

5.7 Verification and Validation

TOPSIS and BWM are verified against the requirements established with the company, confirming that all conditions are met. Validation also involves feedback from company experts and consistency ratio checks of the BWM. Experts find the results convincing but note the importance of operational familiarity, highlighting the need to explore how to include subjectivity in the process. Additionally, they mention the challenge of independently verifying environmental scores. Despite these concerns, applying BWM with TOPSIS is deemed effective, aligning well with user needs and expectations.

6. Conclusion

This study successfully develops a robust Multi-Criteria Decision-Making (MCDM) framework integrating the Best-Worst Method (BWM) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to improve the carrier selection process for the overseas transport of tank containers. The framework effectively incorporates sustainability objectives, balancing economic, social, and environmental criteria. Through systematic identification and weighting of criteria, the results show that economic criteria significantly influenced carrier rankings, with price, IMO surcharge, and transit-time being the most critical factors. Including sustainability criteria, such as CO2 emission per shipment and compliance with sustainability regulations, affects carrier evaluations. This demonstrates that carriers with better environmental performance can achieve higher rankings despite slightly higher costs. The evaluation of carriers across three important shipping lanes shows the framework’s capability to provide a comprehensive and transparent assessment, revealing cost differences compared to traditional lexicographic ordering. This indicates that integrating sustainability into carrier selection is feasible and possible without significant additional costs.

Sensitivity analyses reveal that including sustainability criteria results in noticeable changes in carrier rankings. When economic, social, and environmental criteria are equally weighted, carriers with strong social and environmental performance are favored. Adjustments in economic criteria weights, such as price and IMO surcharges, show that minor changes can reorder carriers, highlighting the significant influence of these criteria. Additionally, reducing the weight of the economic category can have a substantial effect. Finally, validation shows that While experts find the results convincing, they highlight the need for including operational familiarity, incorporating subjectivity, and the challenge of verifying environmental scores.

This research significantly contributes to the body of knowledge on sustainable carrier selection for overseas tank container transport. It demonstrates that integrating sustainability criteria into carrier selection is feasible without significant additional costs, promoting more sustainable and responsible practices. The combined BWM and TOPSIS approach offers a systematic method for carrier selection, aligning with sustainability goals and enhancing decision-making transparency, leading to long-term environmental and social benefits.

7. Discussion

This study has important implications for the selection of carriers seeking to 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. This study offers nuanced insights into carrier selection by integrating comprehensive sustainability criteria, addressing a critical gap in the literature that mainly focuses on operational and economic fac- tors. It demonstrates that using BWM, instead of traditional methods like AHP, can be used for decision-making in carrier selection. By including economic, social, and environmental dimensions, the research aligns with global sustainability goals, reducing carbon footprints and promoting responsible business practices. Practically, this research provides logistics managers with a refined approach to evaluate carriers based on costs and their broader environmental and societal impacts, mitigating operational risks and supporting sustainable development goals in the logistics sector.

This research has several limitations. Some carrier scores are based on assumptions that may not fully reflect reality, and decision-makers may have shown positive bias in pairwise comparisons, potentially overstating certain criteria. The study involved only three decision-makers, and focused on one region, limiting its generalizability and reliability. Considering more decision-makers and robust data sources for environmental scores could improve this. External factors such as conflicts and rate disruptions may have influenced priorities and data which may have distorted reality. Scenario analyses indicate that small changes in scores and weights can significantly impact evaluations, highlighting the need for continuous review and adjustment. Additionally, the inability to incorporate subjectivity and reliance on static criteria and weights may lead to incomplete and biased evaluations. Future research should include subjective criteria and consider operational practices to enhance the decision-making process and ensure relevance.

Future research should explore incorporating operational familiarity and enhancing the verification of environmental scores to further refine the framework's applicability and reliability. Incorporating subjective criteria, such as preferences from surveys or expert opinions, into BWM and TOPSIS allows for a more comprehensive assessment of carrier performance. Besides, expanding the study to different company regions would provide insights into regional challenges and evaluate the effectiveness of this approach across diverse environments. Additionally, involving more decision-makers from various regions or business units and conducting focus groups or workshops could clarify their perspectives and improve the accuracy and reliability of the evaluation process. Measures to reduce potential biases in decision-makers' pairwise comparisons should also be explored. Finally, applying other MCDM methods, such as AHP, could further validate the results and improve accuracy and reliability.

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