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Selecting the Most Economical Ship Type for the Marine Business Investor: A Hybrid Approach with PSI-PIPRECIA-COCOSO Methods

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Abstract

The demand for maritime transportation is experiencing a notable surge in line with the growth in international trade. Turkey's rising import and export figures are facilitating the country's ability to procure and distribute a greater volume of products. This expansion has led to a considerable increase in the number of ships purchased by maritime companies operating in Turkey. However, this situation indicates that there are deficiencies in choosing the most appropriate ship type for the investments to be made by ship operator investors. The ship selection process is of critical importance for investors to minimize their costs and increase the profitability of their investments. In this study, a hybrid approach was developed using F.PSI-PIPRECIA-CoCoSo methods in choosing the most economical ship type for maritime companies operating in maritime transportation. The research analyzes this data by collecting data through surveys on different ship types and the criteria effective in their selection. The findings show that criteria such as operating costs, environmental impact, income potential and efficiency are at the forefront among ship types. Within the framework of the findings obtained, ships used for energy purposes were determined as the best ship type to invest in. LPG tankers came in second and oil tankers came in third. As a result, this study presents a methodology that will assist maritime transportation investors in selecting the most economically suitable ship type and shows similarities and differences with studies in literature. The developed hybrid method draws attention with its applicability and effectiveness in decision-making processes and functions as a tool to support investors' strategic decisions.

Key words: Maritime Management, Ship Selection, F.PSI-PIPRECIA-COCOSO, Economic Ship Types, Ship Management.

JEL Code: M11, M13, M19

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1. Introduction

Maritime transport is one of the most important elements of world trade, and investments in this sector play a critical role in terms of economic growth and the development of global trade. As of 2020, it has been observed that 80% of the total amount of cargo transported by sea was carried out by maritime transport (Ceyhun, 2023). This statistic clearly shows the central role and importance of maritime transport in world trade. Maritime transport increases the efficiency of international trade and makes significant contributions to global economic integration by offering lower costs and higher carrying capacities compared to other modes of transportation (Arıcan, 2023). It is important to analyze investment behaviors in maritime transport, to reveal how these dynamics affect decision-making processes in the sector, and to provide important information about investors' decision-making processes in this context (Fan and Luo, 2013).

However, maritime transportation investments depend not only on selecting appropriate ship types, but also on considering environmental impacts, operating costs, and market conditions. At this point, the importance of determining ship selection criteria should be emphasized and the effects of these factors on investment decisions should be examined in depth (Arıcan and Kara, 2022). There are many criteria that investors should consider when selecting a ship type; these include carrying capacity, operating costs, environmental impacts of the ship, energy efficiency, and market conditions (Zhong-Zhen and Jun, 2013). Therefore, the process of choosing the most economical and efficient ship type for maritime transportation investors is becoming increasingly complex.

The ship selection process is a multi-criteria decision-making process in which many factors must be considered (Fan and Luo, 2013). There are different alternatives among ship types such as bulk carriers, container ships, chemical tankers, Roll on Roll off (Ro-Ro) ships, oil tankers, dry cargo ships, energy ships and Liquid Petroleum Gas (LPG) tankers (Arıcan et al., 2022). Each ship type differs in terms of various criteria such as carrying capacity, operating costs and environmental impacts (Sener, 2016). This situation makes it difficult for investors to determine which ship type is most suitable for them. In particular, the types of cargo carried by ships directly affect the efficiency and productivity of each ship type. It is important to develop multi-criteria ship selection procedures and to detail how these criteria will be integrated (Grubišić et al., 2000).

The selection of the appropriate ship type in maritime transportation affects not only costs but also environmental sustainability. Modern ships aim to minimize their environmental impacts with less energy consumption and low emission levels (Kana, 2017). It shows that models that predict decision-making processes in ship design should be developed, and new perspectives should be presented on how to relate these processes to environmental impacts (Kana, 2017). In addition, the energy efficiency of ships and their compliance with environmental standards have become important criteria for investors. Increasing environmental regulations encourage investors to turn to environmentally friendly ship alternatives (Ceyhun and Özbağ, 2014). The importance of environmental sustainability in maritime transportation and the necessity of taking measures against environmental impacts are important (Yan et al., 2021). This situation provides investors with a new perspective on how to consider environmental criteria in ship selection.

Another important criterion for maritime business investors to consider when choosing the most economical ship type is the market value and competitive position of the ship (Okşaş, 2023). The impact of market conditions on ship selection and perspectives on how these impact criteria should be integrated have become an important phenomenon for ship management (Yan et al., 2022). The ship's characteristics, areas of use and the types of cargo it carries determine the ship's impact on the market. In addition, ship operators and owners should make their ship selections in accordance with market conditions and minimize operating costs (Kara et al., 2022). Factors such as market dynamics and cargo demand play an important role in the ship selection process.

Another important criterion that investors should consider in their decision-making processes is the operating costs of ships (Arıcan et al., 2023). Operating costs include many factors such as maintenance, insurance, personnel expenses and fuel consumption, in addition to the purchase price of the ship (Qiao et al., 2024). The management of these costs is a very critical issue for investors (Efecan, 2024). Cost analyses for chemical tankers, which are considered sensitive and difficult in terms of ship type, have been examined in depth for ship operating investors and it has been seen that many factors, including ship fixed equipment, are important (Arıcan and Kara, 2024). It emphasizes the importance of cost analysis in investors' decision-making processes (Efecan, 2023). At the same time, ship operators should act with the aim of minimizing costs in current market conditions and make their ship selections accordingly (Yan et al., 2022).

The aim of the study is to determine the most economical ship type for maritime transportation investors and to detail the application process of the methods to be used in this process. In the ship selection process, an evaluation will be made by considering criteria such as operating costs, environmental impacts, income potential and efficiency. In this context, using the F.PSI (Fuzzy Preference Selection Index)-PIPRECIA (Preference Index for Pairs of Criteria)-CoCoSo (Combination of Compromise Solutions) methods will be revealed how to evaluate existing ship alternatives according to market conditions. The main reason for choosing F.PSI-PIPRECIA-CoCoSo methods as a combination is that these methods combine different strengths in multi-criteria decision making (MCDM) processes. While F.PSI minimizes uncertainty by allowing the criteria to be evaluated with fuzzy logic, PIPRECIA offers a flexible approach in determining the relative importance of the criteria. CoCoSo allows for a compromise combination of solutions. This combination provides both a comprehensive and balanced analysis for the economic evaluation of ship types. Compared to other common MCDM methods, these advantages of the selected methods make them more appropriate, especially in a complex and multi-criteria context such as maritime transport. In addition, how these methods will be integrated as a hybrid approach and their contributions to the ship selection process will be detailed.

The maritime transport sector, responsible for 80% of global trade, faces increasing pressure to align operational efficiency with environmental and economic goals. Maritime investors must navigate complex decisions influenced by fluctuating market conditions, stringent environmental regulations, and diverse ship types with varying operational profiles. Despite the critical role of ship selection in minimizing costs and maximizing returns, existing methodologies often fail to integrate environmental sustainability and market responsiveness effectively. This study addresses these gaps by leveraging a PSI-PIPRECIA-CoCoSo hybrid approach to identify the most economical ship type, providing a robust decision-making framework that aligns with contemporary industry demands.

The structure of this study is as follows: Section 2 examines the ship type selection process in maritime transport and the existing literature. Section 3 details the hybrid method used in the study and compares this method with similar studies in literature. In addition, the mathematical Equations used, and the applicability of the methods are emphasized. The findings are presented in Section 4, the criteria considered in ship type selection and the obtained evaluation results are explained in detail. Section 5 discusses the effects of these findings on the practices in the sector, and the similarities and differences in the literature are emphasized. Finally, Section 6 concludes the study by summarizing the results obtained in ship type selection in the maritime transport sector and their contributions to future research.

2. Literature Review

Maritime transport is an important component of global trade, and the selection of different ship types is a critical decision affecting the costs of investors. Ship selection processes are a complex process that requires the evaluation of many criteria. In this section, current studies in the literature on ship selection methods will be included. These studies examine the analysis of various criteria in the ship selection process and their potential to increase cost, efficiency and operational effectiveness.

Yan et al. (2022) examined ship selection processes within the framework of port state control, identifying key criteria and discussing implementation processes to enhance efficiency. The study highlights the significance of a multi-criteria approach, further demonstrating the potential of artificial intelligence models to improve ship selection outcomes, even with imbalanced datasets. Similarly, Xie et al. (2008) analyzed ship selection using a multi-criteria synthesis approach, advocating for the joint evaluation of diverse criteria and showcasing the effectiveness of these techniques in comparing ship types and addressing complex decision-making challenges.

In the broader context of maritime transportation, Sener (2016) evaluated ship selection criteria, emphasizing factors such as operating costs, environmental impact, and income potential. The study provided strategic insights for ship investors by expanding the scope of relevant criteria. Qiao et al. (2024) applied optimization techniques to ship selection and inspection planning in inland waterways, highlighting the importance of these methods in ensuring efficient transportation. Furthermore, Grubišić et al. (2000) proposed a standardized model for evaluating multiple criteria in ship selection, offering a procedural framework for decision-makers.

Considering market dynamics, Zhong-zhen and Jun (2013) explored the impact of fluctuations in trade goods on ship selection for container transportation, underscoring the necessity of integrating market conditions into decision-making. Fan and Luo (2013) focused on ship investment behavior in liner shipping, illustrating how economic factors influence ship selection and providing actionable insights for investors. Arıcan and Kara (2022) contributed to this domain by identifying chemical tanker selection criteria, and in a subsequent study (2024), developed a fuzzy Analytical Hierarchy Process (AHP)- Technique for Order Preference by Similarity (TOPSIS)-based model to address uncertainties in chemical tanker selection.

Lastly, Kana (2017) modeled decision-making processes in ship design, analyzing the strengths and limitations of various approaches. Collectively, these studies underline the importance of multi-criteria and optimization techniques, as well as the integration of market dynamics, environmental considerations, and advanced decision-making models in ship selection processes.

This literature review reveals the importance of application areas of multi-criteria analysis methods in ship selection. Current studies help ship investors make the right choices and offer suggestions for making processes more efficient. The diversity of criteria used in ship selection is an important factor affecting investors' costs, and continuing studies in this area will increase knowledge in the sector.

There are many studies in the literature on ship selection in the maritime transport sector; however, these studies have generally focused on specific ship types, topics or limited criteria. In this study, the aim is to develop a selection model for all ship types and in economic terms. In addition, the use of the PSI-PIPRECIA-CoCoSo method, which has never been used in other studies, as a hybrid approach in this study aims to provide a more comprehensive analysis by going beyond existing methods. Thus, it is expected to provide more data on the applicability and effectiveness of these methods.

Table 1 provides summaries and main findings of similar studies in literature:

Table 1. Summary of similar studies on ship selection.

Authors	Year	Journal Name	Working Title	Main Finding
Grubisic, I. et al.	2000	In International Design Conference-Design 2000	Multi-criteria ship selection procedure	Contribution was made to the standardization of ship selection processes.
Xie, X. et al.	2008	Journal of Marine Science and Technology	Ship selection using a multiple-criteria synthesis approach	It has been revealed that different criteria should be evaluated together in ship selection.
Fan, L. & Luo, M.	2013	Maritime Policy & Management	Analyzing ship investment behavior in liner shipping	The effect of economic factors on ship selection was investigated.
Zhong-zhen, Yang & Jun, Zhao	2013	Journal of Transportation Systems Engineering and Information Technology	Ship Selection of Container Transport Based on Trade Goods Fluctuation	It has been stated that market conditions should be taken into consideration in the ship selection process.
Sener, Z.	2016	Journal of Advanced Management Science	Evaluating ship selection criteria for maritime transportation	Ship selection criteria are discussed in a broad scope.
Kana, AA	2017	Ocean Engineering	Forecasting design and decision paths in ship design	A study was conducted to model decision-making processes in ship design.
Arican, O.H. & Kara, G.E.	2022	Mersin University Journal of Maritime and Logistics Research	Determination of Chemical Tanker Selection Criteria for Shipping Companies	Selection criteria for chemical cargo transportation have been determined.
Yan, R. et al.	2022	Transportation Research Part C: Emerging Technologies	Efficient and explainable ship selection planning in port state control	The effectiveness of artificial intelligence models in ship selection has been investigated.
Yan, R., Wang, S., & Peng, C.	2022	Maritime Policy & Management	Ship selection in port state control: status and perspectives	The importance of a multi-criteria approach in ship selection was emphasized.
Qiao, X. et al.	2024	Mathematics	Ship Selection and Inspection Scheduling in Inland Waterway Transport	The importance of optimization techniques in ship selection for inland waterways is emphasized.
Arican, O.H. & Kara G.E.	2024	Regional Studies in Marine Science	Selection model of chemical tanker ships for cargo types using Fuzzy AHP and Fuzzy TOPSIS	Emphasis was placed on addressing uncertainties in chemical tanker ship selection.

Source: Edited by the author from literature.

3. Methodology

In recent years, multi-criteria decision making (MCDM) methods have been widely used in complex decision-making processes. These methods help to determine the best option among alternatives by considering various criteria. In this context, hybrid approaches such as AHP, TOPSIS, Elimination and Choice Translating Reality English (ELECTRE) and The Decision-Making Trial and Evaluation Laboratory (DEMATEL) facilitate the selection process between ship types and allow for more effective decisions. In the methods used in the hybrid approach used in this study, PSI helps to determine the preference order of alternatives; PIPRECIA is a method for evaluating the relationships between criteria pairs. CoCoSo provides a balance to determine the best option among alternatives. In 2021, Ulutaş et al. stated that they determined the selection of the most suitable transportation company by using these three hybrid methods and put it in the literature (Ulutaş et al., 2021).

The reason behind the choice of the F.PSI-PIPRECIA-CoCoSo method combination is the strong advantages that each method brings to the decision-making processes in the maritime transport context. The F.PSI method uses fuzzy logic to model decision makers' evaluations more realistically in situations where uncertainties and subjectivity are high (De Asis et al., 2024). It minimizes the uncertainties encountered during the evaluation of economic, environmental and technical criteria in ship selection in maritime transport.

PIPRECIA, this method of determining the relative importance of criteria allows decision makers to evaluate interrelated criteria in a more flexible and hierarchical structure (De Sousa et al., 2024). This optimizes the prioritization of criteria in a multivariate context such as maritime transport.

CoCoSo, on the other hand, combines consensus solution methods and ranks alternatives with both simple computational steps and mathematical accuracy (Lucas et al., 2024). It provides a balanced result by considering various criteria in the selection of economic vessels.

In a multivariate and dynamic context such as maritime transport, this selected combination effectively manages the relationships and uncertainties between criteria, while at the same time guaranteeing that the results are both flexible and robust (Mahendra and Wiradika, 2024). Compared to other popular MCDM methods, this combination offers a more holistic perspective in the selection of ship types. For example, while methods such as TOPSIS or AHP cannot fully manage the uncertainties between criteria, F.PSI's fuzzy approach fills this gap. Similarly, PIPRECIA's flexible weighting method and CoCoSo's consensus solution capability make it more comprehensive and reliable.

In this section, first the determination of experts, then the alternative ship types and finally the detailed explanation of the mathematical methods to be used in the study will be given.

Determination of experts

To determine the criteria, 5 ship fleet managers and 3 ship chartering managers working in ship type selection in Turkish shipping companies were contacted. The ship selection criteria in the literature were discussed and then a survey was conducted to determine the criteria. This survey also included open-ended questions. The criteria sent by 8 experts were collected and 4 common criteria were taken into the study. The experts are managers who have worked in the sector for at least 10 years and are considered experts in their fields. According to Hogarth (1978), to obtain the best results, expert opinions should be between 8-12 people. Table 2 shows the years of experience of the experts, the total number of ships in their companies and the tonnage ranges of the ships managed by these experts.

Table 2. Characteristics of experts.

	Rank	Experience (Years)	Education Level	Number of ships	Tonnage Range (DWT*)
Expert 1	SFM**	15	Master D.	9	10,000-100,000
Expert 2	SFM	12	Graduate	8	10,000- 80,000
Expert 3	SCM***	13	Doctoral	9	20,000-15,000
Expert 4	SFM	14	Graduate	10	30,000-100,000
Expert 5	SFM	12	Graduate	11	20,000- 80,000
Expert 6	SFM	11	Master D.	12	30.000-90.000
Expert 7	SCM	16	Master D.	8	5,000-100,000
Expert 8	SCM	14	Graduate	9	20,000-120,000

*DWT: Deadweight: The amount of cargo that the ship can carry. **SFM: Ship Fleet Manger. *** SCM: Ship Chartering Manager

Source: Author

Alternatives

The ship alternatives evaluated in the study were determined by experts. The characteristics and descriptions of these ship types are given in Table 3.

Table 3. Ship types and descriptions.

Type of ship	Description
Bulk Carrier	A type of ship that carries cargo (usually dry cargo) in bulk quantities. The cargo carried on this type of ship is loose cargo, meaning it has no specific packaging, and usually includes items such as food grains, ores and coals, and even cement.
Container Ship	A ship specially configured to hold large amounts of cargo compressed in different types of containers is called a container ship (vessel).

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Chemical Tanker	Chemical tanker ships are ships specialized for carrying large amounts of liquid chemical bulk cargo.
Ro-Ro	Ro-Ro is short for Roll-on/roll-off. Roll-on/roll-off ships are ships used to carry wheeled cargo.
Oil tanker	Oil tankers are large and mostly carry crude oil and its by-products.
Dry Cargo Ship	They are smaller ships like bulk carriers with their own crane equipment. They mostly carry solid or unshaped loads.
Energy Ship	It is a special purpose ship type that is designed to produce energy and does not sail.
Gas Tanker	A gas carrier (or gas tanker) is a highly secure tanker designed to transport LPG, LNG or liquefied chemical gases in bulk.

Source: Dalsøren et al., 2009.

Hybrid Methods

In the study, F.PSI, PIPRECIA and CoCoSo methods were used together to determine the most economical ship type in the maritime sector. The applicability and effectiveness of the method will be shown by how similar methods were used in previous studies. In this context, a summary table of the methods obtained from the studies specified in Table 4 is presented:

Table 4. Some usage examples of the methods used in the study in the literature.

Authors	Year	Working Title	Journal Name	Method	Purpose of Use
Ulutas et al.	2021	A new hybrid fuzzy PSI-PIPRECIA-CoCoSo MCDM based approach to solving the transportation company selection problem	Technological and Economic Development of Economy	PSI-PIPRECIA-CoCoSo	Choosing a transportation company
Uluta et al.	2021	Selection of insulation materials with PSI-CRITIC based CoCoSo method	Revista de la Construcción,	PSI-CRITIC-CoCoSo	Selection of insulation material
Popovic	2021	An MCDM approach for personnel selection using the CoCoSo method	Journal of process management and new technologies	CoCoSo	Personnel selection
Mahendra & Wiradika	2024	Decision Support System for Selection of Favourite Tourist Attractions Using PIPRECIA-CoCoSo with Python Implementation using PIPRECIA-CoCoSo	Teknomatika	PIPRECIA-CoCoSo	Selection of tourist attractions

DeSousa et al.	2024	Application of the PSI-CoCoSo Hybrid Method in the Choice of Light Fleet Supplier for a Logistics Distribution Center	ICMCSI	PSI-CoCoSo	Supplier selection for logistics distribution center
Lucas et al.	2024	Valuation of Real Estate Investment Trusts using the PSI-CoCoSo Multicriteria Method	Computer Science	PSI-CoCoSo	Evaluation of real estate investments
De Assis et al.	2024	Use of the PSI-CoCoSo Method in the Evaluation of Imagers for use in Helicopters of the Military Police of the State of Rio de Janeiro	ICMCSI	PSI-CoCoSo	Evaluation of imaging systems for military helicopters

Source: Edited by the author from literature.

The F.PSI-PIPRECIA-CoCoSo method used in the study was developed by utilizing the findings of the above-mentioned studies. This triple method draws attention with its ability to manage uncertainties while addressing the complexity of multi-criteria decision-making processes (Uluta et al., 2021). In addition, the hybrid structure used to evaluate the interactions of different criteria with each other will provide results aimed at increasing the economic efficiency of ship types. Similar application areas in studies such as Ulutaş et al. (2021) and De Sousa et al. (2024) reveal the practicality and effectiveness of this method in a wide range of sectors. In this context, the methodology of the research will be used as an effective tool in determining the valid criteria and alternatives for the ship types to be selected. The mathematical foundations of these methods are explained in the following sections.

Fuzzy PSI (Fuzzy Preference Selection Index) Method

Fuzzy logic is used to better manage uncertainty and subjective decision processes. The PSI method allows alternatives to be evaluated according to criteria.

Step 1: Creating Fuzzy Decision Matrix

The performance values of the alternatives for each criterion are expressed as fuzzy numbers. These fuzzy numbers are usually represented as triangular fuzzy numbers (FTN) as in Equation (1) (Luas et al., 2024):

$$\tilde{A} = (a_1, a_2, a_3) \quad (1)$$

Here,a_1 is the minimum value of the fuzzy number; is $a_2$the most probable value; $a_3$and is the maximum value. For example, the Operating Costs criterion for the ship ɵ can be fuzzified as equation 2:

$$\widetilde{A} = (0.6, 0.8, 1.0) \quad (2)$$

Linguistic variables and fuzzy numbers are shown in table 5.

Table 5. Fuzzy number expressions of linguistic variables.

Linguistic variables	Fuzzy numbers
Very high	(0.9, 1.0, 1.0)
High	(0.7, 0.9, 1.0)
Medium high	(0.5, 0.7, 0.9)
Middle	(0.3, 0.5, 0.7)
Medium low	(0.1, 0.3, 0.5)
Low	(0.0, 0.1, 0.3)
Very low	(0.0, 0.0, 0.1)

Source: Stanujkic, 2015.

Step 2: Normalization

For each criterion, the fuzzy values are normalized. If the criterion is positively oriented, the normalization of the fuzzy numbers is specified as in Equation (3) (Ulutas et al., 2021):

$$\widetilde{N}_{ij} = \left(\frac{a_{1ij}}{Max\ a_{3j}}, \frac{a_{2ij}}{Max\ a_{3j}}, \frac{a_{3ij}}{Max\ a_{3j}}\right) \quad (3)$$

If the criterion is negatively oriented, the normalization is established by specifying Equation (4):

$$\widetilde{N}_{ij} = \left(\frac{Min.a_{1j}}{a_{3ij}}, \frac{Min.a_{1j}}{a_{2ij}}, \frac{Min.a_{1j}}{a_{1ij}}\right) \quad (4)$$

This normalization process makes criteria at different scales comparable to each other.

Step 3: Calculating PSI Values

For each alternative, PSI_iits value is calculated as in Equation (5):

$$\mathrm{PSI_i} = \sum_{j=1}^{m} \mathrm{w_j} . \widetilde{\mathrm{N}}_{\mathrm{ij}} \quad (5)$$

Here w_j, represents the weight of the criterion; $\widetilde{N}_{ij}$ represents the normalized performance of the alternative. PSI_i Its value shows the overall performance of the alternatives. Fuzzy numbers are created using the given minimum, medium and maximum scores. Then, the normalized decision matrix is created for each criterion. Finally, the weights are determined, and PSI scores are calculated (De Sousa et al., 2024).

PIPRECIA (Pair-to-Pair Relative Criteria Importance Assessment)

PIPRECIA is a method used to determine the relative importance of criteria. This method allows decision makers to determine the order of priority among criteria.

Step 1: Ranking the Criteria

Decision makers rank the criteria in order of importance and determine a relative importance score for each criterion (Setiawansyah and Saputra, 2023).

Step 2: Calculating Relative Weights
The weights of the criteria are calculated by Equation (6):

$$k_j = 1 + \left(\frac{s_j + 1}{s_j}\right) \tag{6}$$

Here, S_j refers to the relative importance score of the criterion. Then, the normalized weights of the criteria are found as in Equation (7) (Dalic et al., 2020):

$$w_j = \left(\frac{k_j}{\sum_{j=1}^{n} k_j}\right) \tag{7}$$

Here, the weights of the criteria are calculated according to their importance levels. And a total score is created for each ship type by considering the weight of each criterion (Sulistani et al., 2023).

CoCoSo (Combined Compliance Solution) Method

The CoCoSo method is used to calculate the overall performance of the alternatives and provides a harmonized ranking. This method combines the weight and performance scores obtained by the PSI and PIPRECIA methods.

Step 1: Calculating Individual Values

For each alternative, the values of $\boldsymbol{S_i}$ and $\boldsymbol{K_i}$ are calculated with the help of Equations (8) and (9) (Mahandra, 2021):

$$S_i = \sum_{j=1}^{m} w_j \,.\, \widetilde{N}_{ij} \tag{8}$$

$$K_i = \prod_{j=1}^{m} \left(\widetilde{N}_{ij}^{wj}\right) \tag{9}$$

Step 2: Calculating the Final Score

The final performance score of each alternative is calculated with the help of Equation (10) (Luas et al., 2024):

$$CoCoSo_i = \propto . \left(\frac{S_i}{Max\ S_i}\right) + \beta . \left(\frac{K_i}{Max\ K_i}\right) \tag{10}$$

Here, $\propto$and $\beta$are the weighting factors (usually $\propto$=, β=0.5) (De Asis et al., 2024).

Step 3: Ranking

The alternatives $CoCoSo_i$are ranked according to their scores. The alternative with the highest score is selected as the most suitable ship type. Calculations are made based on criteria using the weights obtained from PIPRECIA. In the next stage, the CoCoSo score is calculated, and the alternatives are ranked.

This hybrid method used in the study facilitates the integration of data obtained from various sources. The combined use of F.PSI, PIPRECIA and CoCoSo methods creates a more robust decision-making process by bringing together different data types and sources. This increases the data quality and reliability of the study.

4. Findings

Determination of Ship Type Selection Criteria

The criteria stated and agreed upon as a common opinion by the experts in the study are given in Table 6. The weightings of these main criteria were determined by calculating according to Equation 6.

Table 6. Criteria and weightings to be used in ship type selection.

Criterion name	Description	Weighting
Operating Costs	Fuel, maintenance, crew expenses.	0.30
Environmental Impact	Carbon emissions, energy efficiency.	0.20
Income Potential	Annual rental and freight income.	0.25
Productivity	Load capacity, speed and fuel consumption.	0.25

Source: Authors' Calculations

Table 6 outlines the key criteria, and their respective weightings used in the decision-making process for selecting the most suitable ship type. The criteria are evaluated based on their importance, as reflected by their assigned weightings, which sum to 1. Operating Costs, with the highest weighting, highlight the financial implications of ship operations. It includes expenses related to fuel consumption, routine and extraordinary maintenance, and crew wages. The emphasis on operating costs indicates that economic efficiency is a primary concern in ship selection, as these expenses directly impact profitability. The second criterion assesses the ship's sustainability credentials, considering factors such as carbon emissions and energy efficiency. A weighting of 0.20 reflects the growing importance of environmental considerations due to global regulatory pressures and increasing societal focus on green shipping.

Evaluation of Economic Performance of Ship Types by Experts

The geometric means of the scores of the ship types on a scale of 1 (very low) to 10 (very high) according to the criteria stated and agreed upon as a common opinion by the experts in the study are given in Table 7.

Table 7. Scoring ship types by criteria by experts.

Criterion	Ship Type	Minimum Score (min)	Mid Score (mid)	Maximum Score (max)
Operating Costs	Bulk Carrier	2	5	7
	Container Ship	3	6	9
	Chemical Tanker	4	7	10
	Ro-Ro	3	6	9
	Oil tanker	5	8	10
	Dry Cargo Ship	3	5	8
	Energy Ship	5	8	10
	LPG Tanker	5	7	9
Environmental Impact	Bulk Carrier	3	6	9
	Container Ship	5	8	9
	Chemical Tanker	4	6	9
	Ro-Ro	4	7	10
	Oil tanker	5	7	10
	Dry Cargo Ship	3	6	9
	Energy Ship	6	8	10
	LPG Tanker	4	6	9
Income Potential	Bulk Carrier	2	5	8
	Container Ship	3	5	9

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	Chemical Tanker	4	5	10
	Ro-Ro	3	5	8
	Oil tanker	5	7	9
	Dry Cargo Ship	2	5	7
	Energy Ship	8	9	10
	LPG Tanker	7	8	10
Productivity	Bulk Carrier	2	4	7
	Container Ship	3	5	8
	Chemical Tanker	4	6	8
	Ro-Ro	4	6	8
	Oil tanker	4	6	8
	Dry Cargo Ship	3	5	7
	Energy Ship	8	9	10
	LPG Tanker	7	8	10

Source: Authors' Calculations

The above decision matrix data is normalized by min-max normalization. This step allows comparing the performance of each ship type in terms of different criteria (operating costs, environmental impact, revenue potential, efficiency).

Equations (8) and (9), the fuzzy sum of weighted comparability and the power weight of comparability arrays were calculated $\boldsymbol{K_i}$for each ship type, respectively $\boldsymbol{S_i}$. In calculating these values, the combined weights of the criteria were used as the criterion weights. These values are shown in Table 8.

Table 8. Final scores and rankings of ship types

Alternatives	$\boldsymbol{S_i}$	$\boldsymbol{K_i}$
Bulk Carrier	(0.055, 0.501, 2.799)	(2,448, 6,301, 6,900)
Container Ship	(0.057, 0.511, 2.838)	(2,469, 6,329, 6,921)
Chemical Tanker	(0.061, 0.538, 2.984)	(3,069, 6,365, 6,938)
Ro-Ro	(0.059, 0.511, 2.841)	(2,469, 6,329, 6,931)
Oil tanker	(0.101, 0.601, 2.884)	(4,129, 6,387, 6,929)
Dry Cargo Ship	(0.061, 0.514, 2.840)	(2,469, 6,330, 6,929)
Energy Ship	(0.102, 0.654, 3.237)	(3,641, 6,610, 6,973)
LPG Tanker	(0.091, 0.614, 3.099)	(2,671, 6,469, 6,961)

Source: Authors' Calculations

The above evaluation scores are combined using Equation (10) to obtain the final score $CoCoSo_i$ for each transportation company. The final scores and rankings of ship types are given in Table 9.

Table 9. Final scores and rankings of ship types

Ship Type	Score	Arrangement
Bulk Carrier	0.083333	8
Container Ship	1.116667	5
Chemical Tanker	1.366667	4
Ro-Ro	1.158333	5
Oil tanker	2.016667	3
Dry Cargo Ship	0.291667	7
Energy Ship	3,000,000	1
LPG Tanker	2.070833	2

Source: Authors' Calculations

Table 9 summarizes the final scores and rankings of ship types based on their evaluated performance. The Energy Ship ranks first with the highest score of 3,000,000, indicating its superior suitability. Following closely, the LPG Tanker secures the second position with a score of 2.070, while the Oil Tanker ranks third at 2.016. The Chemical Tanker takes the fourth position with a score of 1.366, and the Container Ship and Ro-Ro share the fifth rank with scores of 1.116 and 1.158, respectively. Lower in the rankings, the Dry Cargo Ship is placed seventh with 0.291, and the Bulk Carrier finishes last in eighth position with 0.083, highlighting its relative inadequacy compared to the other ship types.

5. Discussion

This study applied the PSI-PIPRECIA-CoCoSo method to select the most economical ship type for maritime transport investors and obtained important findings. First, the analysis results showed that certain ship types are more economical and efficient for certain types of cargo. These findings reveal that the criteria to be considered in ship selection are not limited to cost alone, but also environmental impact, operational efficiency and longevity play a critical role. In particular, the data obtained emphasize that maritime business investors should also consider risk management in their decision-making processes.

Among the 4 criteria specified by experts in ship type selection, operating costs emerged as the most important criterion with a coefficient of 0.30. Income potential and efficiency criteria were specified with a weighting coefficient of 0.25. The weight of the environmental impact criterion was specified as 0.20. Here, it is understood that costs, namely fuel, personnel, maintenance and other important items to be performed in ship operation, are important criteria that maritime business investors care about. The fact that environmental impacts are less important to ship operators was not considered positive.

In the selection of ship types, 8 different ship types were evaluated. Energy ships were the most suitable ships in terms of operating cost, environmental impact, income potential and efficiency. The most important feature of these ships was interpreted as having a high-income potential. Since it does not sail, it is important that fuel consumption will be low and that it is continuous in terms of efficiency. Since it is a factory in terms of operating costs, it is more valuable than other criteria.

Another type of ship, LPG gas carrier tankers, was found to be the second most preferred type of ship in the study. It is known that the operating costs of this type of ship are at a medium level. With the use of LNG fuel in new types of gas tankers and the decrease in fuel sulfur rates, almost zero emission ships are being built. The load potential is much higher than other types of ships, which indicates that the income potential is high. In terms of efficiency, since it is one of the ships that can be rented according to fixed loads in certain regions, it can be concluded from the study results that it is efficient both in terms of freight and operational management. In recent years, it has been observed that Turkish shipowners have made serious investments in the ownership and operation of LPG tankers.

The third preferred type of ship, oil tankers, are among the ships with high income potential due to their fixed freight income and high carrying capacity. In terms of efficiency, they are in the appropriate ship category due to their 20–25-year usage period and continuous sales in the second-hand market. Since these types of ships are large, they have high fuel consumption and due to the frequent inerting and crude oil washing (COW) operations in the ship cargo operations, they are among the ships with low environmental impact sensitivity. Operating costs are lower because they are designed for single-type loads, but their daily expenses are also high because they are large. For this reason, it has been revealed from the study that the transportation costs are at a medium level.

The last preferred ship type was dry cargo. It was thought that the operating costs were high due to their own loading and unloading equipment. According to the maritime freight market, the transportation fees per unit ton are low compared to other cargo categories. For this reason, the income potential is low compared to other ship types. On the other hand, it has a low environmental impact, but in terms of efficiency, it is difficult to enter regions where cargo freight is high such as Europe and America over a certain age. When we look at the number of ships in the maritime trade fleet, this type of ship is the most common. It is the last to be preferred in terms of investment potential.

The findings determined in the study show some similarities and differences when compared with various studies in existing literature. Yan et al. (2022) emphasizes the importance of criteria such as cost and environmental sustainability in ship selection. The findings of this study show how these criteria affect the decision-making processes for maritime transportation investors. Similarly, this study also reveals the importance of considering environmental impacts in addition to economic efficiency. However, while Yan et al.'s research focuses more on port state control, this study offers a comprehensive approach to the selection of ship types.

Xie et al. (2008) developed a multi-criteria approach in ship selection. This study emphasizes that many criteria such as cost, reliability and environmental impact should be evaluated together. These findings are parallel to the results of the current study, and both studies reveal that investors should make a multi-dimensional evaluation in their decision-making processes. However, the methods used in Xie et al's study are not as comprehensive as the hybrid approach offered by the PSI-PIPRECIA-CoCoSo method.

In the limitations of the study, maritime businesses in Türkiye were examined based on their investors. The tonnage ranges of ship types were taken as 50,000-60,000 DWT ship scale. The reason for taking this tonnage range is that as the tonnage increases, the operating costs, income potential and environmental impacts of the ships change.

6. Conclusion

In this study, the applicability of the PSI-PIPRECIA-CoCoSo hybrid approach for the selection of the most economical ship type for maritime transport investors was examined. The findings reveal the importance of a multi-criteria assessment in the selection of ship types and the various factors that should be considered in this process. The study emphasizes that not only cost but also environmental impact, operational efficiency and longevity should be taken into consideration.

The applied PSI-PIPRECIA-CoCoSo method provides an effective tool for managing uncertainties in decision-making processes and systematically evaluating alternative ship types. The data obtained provides a solid basis for investors in the maritime transport sector to make more conscious decisions. In addition, the findings obtained in the study are supported by comparisons of how similar methods are used in other studies in the literature. In this way, a broader understanding of maritime transport has been developed.

As a result, this study contributes to existing literature by addressing the complex decision-making processes in ship type selection for maritime transportation investors in a more systematic way. The findings obtained not only support the decision-making processes of maritime business investors, but also provide a guiding framework for decision-makers in the maritime transportation sector. Future research can provide a more comprehensive approach by examining the adaptation of these methods to different maritime transportation types and changing market conditions. In addition, the findings of this study provide suggestions that can assist decision-makers in the maritime transportation sector in their strategic planning processes. As a result, it is concluded that the PSI-

PIPRECIA-CoCoSo method can be used as an effective decision support tool in the ship type selection of maritime transportation investors.

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