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FACTORS CONSTRAİNİNG OPERATİONAL EFFİCİENCY IN MARİTİME TRANSPORTATİON: A COMPARATİVE ANALYSİS OF QUANTİTATİVE DECİSİON SUPPORT MODELS AND FİELD REALİTİES

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Abstract

This study aims to identify the key risk factors that constrain operational efficiency in international maritime transport and to conduct a comparative analysis of the performance of the six continents addressed in line with these factors. The research is based on a hybrid research design that combines qualitative field observations with quantitative decision support models. Within the scope of the study, seven key criteria were considered: port congestion, bureaucratic barriers, security/piracy, technical and fuel issues, personnel issues, environmental conditions, and geopolitical risks. Based on these criteria, Europe, North America, South America, Asia, Africa, and Oceania were compared in terms of operational risks. The research working group consisted of three senior ship captains with a cumulative 60 years of sectoral experience. Semi-structured interviews and pairwise comparison matrices were used as data collection tools. In the analysis of the data, the Best-Worst Method (BWM) was applied for criterion weighting and the Simple Additive Weighting (SAW) method was applied for continent ranking, and the findings were validated using the Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methods. According to the analysis results, bureaucratic barriers have been identified as the most dominant operational constraint in maritime trade. This finding indicates that the fundamental disruptions in the sector stem from the costs of informal transactions, expressed through concepts such as the "Marlboro Canal," rather than technical inadequacies. In regional analyses, Europe was found to be the continent with the highest operational performance, while Asia and Africa were identified as the regions with the highest risk intensity. In light of the research findings, it is recommended that "Single Window" digital declaration systems, which minimise the risk of corruption, be widely implemented, particularly in developing ports, and that security protocols be made more transparent.

Keywords: *Maritime transportation, Operational efficiency, Expert judgment, Best-Worst Method (BWM), Multi-Criteria Decision Making (MCDM).*

JEL Codes: *R41, L91, R49, C44.*

Denizyolu Taşımacılığında Operasyonel Verimliliği Kısıtlayan Faktörler: Sayısal Temelli Karar Destek Modelleri ve Saha Gerçeklerinin Karşılaştırmalı Analizi

Öz

Bu çalışma, uluslararası denizyolu taşımacılığında operasyonel verimliliği kısıtlayan temel risk faktörlerini belirlemeyi ve bu faktörler doğrultusunda ele alınan altı kıtanın performanslarını karşılaştırmalı olarak analiz etmeyi amaçlamaktadır. Araştırma, nitel saha gözlemleri ile nicel karar destek modellerini birleştiren hibrit bir araştırma deseni üzerine kurgulanmıştır. Çalışma kapsamında, liman sıkışıklığı, bürokratik engeller, güvenlik/korsanlık, teknik ve yakıt sorunları, personel sorunları, çevresel koşullar ve jeopolitik riskler olmak üzere yedi temel kriter ele alınmıştır. Bu kriterlere göre Avrupa, Kuzey Amerika, Güney Amerika, Asya, Afrika ve Okyanusya kıtaları operasyonel riskler bakımından karşılaştırılmıştır. Araştırmanın çalışma grubu, kümülatif olarak 60 yıllık sektörel tecrübeye sahip üç kıdemli gemi kaptanından oluşmaktadır. Veri toplama aracı olarak yarı yapılandırılmış görüşmeler ve ikili karşılaştırma matrisleri kullanılmıştır. Verilerin analizinde, kriter ağırlıklandırma için BWM (Best-Worst Method) ve kıta sıralaması için SAW (Simple Additive Weighting) yöntemi uygulanmış ve bulgular, AHP (Analytic Hierarchy Process) ve TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) yöntemleri ile doğrulanmıştır. Analiz sonuçlarına göre bürokratik engeller, deniz ticaretindeki en baskın operasyonel kısıt olarak belirlenmiştir. Bu bulgu, sektördeki temel aksamaların teknik

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yetersizliklerden ziyade "Marlboro Kanalı" gibi kavramlarla ifade edilen kayıt dışı işlem maliyetlerinden kaynaklandığını teyit etmektedir. Bölgesel analizlerde Avrupa, en yüksek operasyonel performansa sahip kıta olarak öne çıkarken, Asya ve Afrika kıtaları manuel kayıt sistemleri ve güvenlik rantı gibi faktörler nedeniyle risklerin en yoğun yaşandığı bölgeler olarak saptanmıştır. Araştırma sonuçları ışığında, özellikle gelişmekte olan limanlarda yolsuzluk riskini minimize edecek "Tek Pencere" (Single Window) dijital beyan sistemlerinin yaygınlaştırılması ve güvenlik protokollerinin şeffaflaştırılması önerilmektedir.

Anahtar Kelimeler: *Denizyolu taşımacılığı, Operasyonel verimlilik, Uzman görüşü, Best-Worst Method (BWM), Çok Kriterli Karar Verme (ÇKKV).*

JEL Kodları: *R41, L91, R49, C44.*

1. Introduction

Maritime transport is one of the primary mechanisms of the global economy and is vital to international trade and supply chain continuity. Maritime transport facilitates in excess of 80 percent of worldwide commercial goods. Because of its low cost and capability to transport large quantities of goods over long distances, maritime transport is considered to be the most vital part of international integration. The extensive maritime transport operations face challenges from multilayered risks. These include geopolitical risks, bureaucratic risks, port infrastructure risks, and security risks. These risks can cause fluctuations in international trade. These fluctuations can affect supply security in a wide range of areas. These areas include raw material supply to final consumer prices. Therefore, precise determination of weights and regions of obstacles in maritime transport is of vital importance to strategic decision-makers and stakeholders (Munim & Schramm, 2018).

In the literature, risks associated with maritime transport have generally been addressed in terms of technical failures, weather conditions, or human error (Luo & Shin, 2019). However, recent global crises and digitalisation processes in the maritime sector have altered the nature of risk. In the present day, bureaucratic corruption, obscurity in customs procedures, and operational slowdowns due to security procedures, which have been referred to as “soft barriers” in addition to physical barriers, have gained prominence (Rezaei et al., 2019). Operational dynamics, which involve the institutionalized culture of bribery in key operational junctures such as the Suez Canal and the artificially created congestion in South American ports due to drug control procedures, require an in-depth scholarly investigation based on the experience of practitioners as opposed to statistical models. In fact, the empirical findings of ship captains with considerable seafaring experience, as presented in the current research, especially those pertaining to the impact of established non-procedural operational dynamics such as the “Marlboro Canal” in key operational junctures such as the Suez Canal, require the findings to be substantiated with the support of quantitative models.

The aim of this particular study is to delve deeper into these seven key factors that affect international maritime trade, including Port Congestion, Bureaucratic Barriers, Security/Piracy, Technical/Fuel Issues, Personnel Challenges, Environmental Conditions, and Geopolitical Risks. This study is based on the direct experience of seasoned ship captains with years of hands-on experience. But, naturally, there is more to this than just a simple list of factors. There is, of course, a discussion of how these factors affect international trade, including six of the seven continents: Europe, Oceania, North America, South America, Asia, and Africa.

In the design of this study, criteria were determined using BWM, while consistency was ensured using AHP. In ranking the continents, the SAW method was applied using the weights determined from the BWM. To ensure the consistency of the ranking, the TOPSIS method was applied using the weights determined from the AHP. Such a complex analytical methodology, using quantitative data-based analysis along with the observations of the captains, makes the study unique in the field of maritime management.

This is not a theoretical study. It is a guide that presents a path for port regions that are upgrading their infrastructure and governance. It is a study that aims to give a clear, data-driven forecast to policymakers and players in the field about the way that global port management practices, such as digitalization, transparent procedures, and accountability, are likely to spread and become established. It is, therefore, a study that is useful, not merely theoretical, as it incorporates actual data along with academic research to reduce operational hurdles.

What is original about this study is the way that the research incorporates both qualitative field research and quantitative multi-criteria decision models. Instead of using existing data, the study uses the experiences of senior ship captains to quantify subjective operational risks. By using the dual validation of BWM-SAW and AHP-TOPSIS, the study presents a tangible performance roadmap, making the study a distinctive guide to global maritime management.

Although the maritime transport literature extensively examines technical, infrastructural and security-related constraints, the effects of institutional and operational “soft barriers” on global supply chain performance remain comparatively underexplored. In particular, bureaucratic inefficiencies, informal transaction costs and operational frictions are often discussed descriptively but are rarely incorporated into structured decision-making frameworks. This study addresses this gap by integrating practitioner-based operational realities with quantitative MCDM approaches and contributes to the theoretical understanding that supply chain efficiency is shaped not only by physical infrastructure but also by institutional quality and procedural governance mechanisms.

In the subsequent sections of the study, a comprehensive literature review on the methodology and criteria used will be presented. This will be followed by a detailed description of the implementation steps. Finally, a comparative analysis of the findings will be provided.

1.1. Literature Review

Maritime transport has an ever-evolving risk landscape due to the dynamic nature of global trade. While existing academic studies generally analyse these risks using statistical data, this study aims to fill the gap in the literature regarding "operational reality" by combining numerical models with the direct field experience of ship captains. In this regard, a comprehensive literature review of both the methodological framework and the academic basis of the defined criteria is presented below.

1.1.1. Literature Review on Methodology

The international maritime trade forms an integral part of the global supply chain, with various risks associated with it, considering different dimensions of risks, such as those resulting from ship operations, environmental, human, and technological risks, among others. Maritime accident and operational risk studies regularly divide causes into the fields of; ship-related, environmental, traffic, and human factors. In this regard, Luo and Shin (2019) divide the causes of accidents into human factors, ship/equipment condition, and environmental, highlighting human error as the principal cause. Relatedly, Jiang et al. (2020) develop Bayesian network models which incorporate vessel condition, environmental, and navigation variables for predicting maritime accident probability. Apart from the cause of incidents, the sustainability of the sector involves the concern of environmental impacts by ship recycling and hazardous materials management.

In tackling the complex problems of the maritime field, MCDM techniques are of considerable importance. The study proposes that the BWM ought to be considered for its capacity to assess the relative importance of each criterion. BWM can be described as the process of assessing the needs of their decision-making role, along with defining what they believe is the worst choice. In comparison, the main techniques that BWM has over others, according to literature, are that they require less input data while providing consistent results relative to AHP. In maritime, BWM has been utilized in studies on assessing port performance, analyzing environmental impacts of ship recycling, and evaluating seafarers' competencies, among others. For instance, Rezaei et al. (2019) used BWM for determining the relative importance of different criteria used in assessing port performance, as well as in the selection of ports, showing that BWM results are consistent with those obtained from assessing stakeholders' preferences. In a similar context, Soner et al. (2022) dealt with hazardous materials by utilizing the Fuzzy extension of BWM to measure the environmental impact of ship recycling. Similarly, Chowdhury et al. (2024) have shown a hybrid approach of utilizing BWM with the Delphi method to gauge the competencies of seafarers. Thus, these studies indicate the effectiveness of BWM in dealing with such complex decision problems in the maritime industry. Additionally, a study of Mi et al. (2019) shows the rising application of BWM for supply chain management and transportation. According to Taherdoost (2023), SAW is characterized as a simple computational process for aggregating the weighted values of the alternatives. SAW is widely recognized to be an efficient procedure for selecting the best option from a number of options for dealing with any kind of decision-making problems.

Besides, the use of AHP and TOPSIS as verification tools has its roots in the existing literature on maritime studies. For instance, AHP assists researchers in resolving complicated issues that are hierarchically structured by analyzing given parameters and aggregating them as a whole. In a similar context of maritime studies, Ugboma et al. (2006) applied AHP to identify shippers' preferences while choosing ports in Nigeria, suggesting that port efficiency is of primary concern. Further, Lirn et al. (2004) applied AHP to analyze factors that global carriers take into consideration while choosing transshipment ports. TOPSIS ranked options based on their distance from the negative ideal solution while also being closest to the positive ideal solution. In a similar context, Arıcan (2025) combined fuzzy AHP and fuzzy TOPSIS as tools for choosing fuel supply vessels, suggesting that these vessels are associated with economic factors as much as they are with operational factors. Furthermore, Shamshol Bahri et al. (2022) comparatively analysed the AHP, TOPSIS, and PROMETHEE methods in the performance evaluation of port personnel, noting that AHP demonstrated the best performance in ranking.

Consequently, the weighting of the criteria determined based on the captain's opinions and literature review with BWM and the ranking of the continents with SAW is consistent with modern decision-making approaches in the literature. The use of the AHP and TOPSIS methods for validation purposes is considered a methodological approach that enhances the reliability of the study.

From the methodological framework described above, the reliability of the tools used in the study of maritime issues becomes evident. However, the fundamental distinction which differentiates this study from similar works lies in the application of these methods, which are usually limited to theoretical models in literature, to convert salient realities of the field, such as "Marlboro Canal" or "Colombian drug searches," into numerical form. The originality of this study may be best highlighted through the analysis of the criteria described below.

1.1.2. Literature Review on Criteria

Maritime transport plays a crucial role as far as the smooth operation of the supply chain is concerned. However, this sector faces multidimensional risks ranging from port operations to security, technical infrastructure to geopolitical balances. This section summarises the existing literature on the criteria obtained from interviews with ship captains and literature reviews.

The problem of port congestion ranks high among maritime logistical bottlenecks, which affect the level of maritime port efficiency and result in increased freight rates. In discussing and defining the problem of port congestion and its effects on maritime transport, Bai et al. (2022a) explained what a port congestion problem is, along with the impacts on maritime and freight shipping. One of the primary impacts is a rise in the amount of time ships need to wait. In a similar vein, Nektarios and Konstantinos (2025) proposed a discussion on the impacts of port congestion, which cause increases in the freight rate of a container ship. In a study done by Trepte and Rice (2014) on the capacities of port infrastructure and bottlenecks within the U.S. port infrastructure system, researchers were able to find and reveal some of the impacts of these bottlenecks on these systems. However, based on data gathered and used for this research, port congestion may not result from poor port and infrastructure systems, such as the ones experienced along the coast of South America, due to very thorough and stringent anti-drug measures, underwater inspections, and cargo inspection at port of call after setting sail.

The efficiency of ports and their maritime operations depends not only on brick-and-mortar infrastructure but also, importantly, on how things are managed - the policies, the procedures, and the routines that govern everyday work. Brooks et al. (2017) investigated how different models of port governance shape port performance in a multi-country investigation into port governance. Chen et al. (2019) also identified that streamlining bureaucratic processes and enhancing cooperation among a wide range of stakeholders is necessary to establish green, smart port governance. More recently, Monios and Wilmsmeier (2022) traced the changes to maritime governance resulting from COVID-19, adjusting to changed market conditions and more stringent environmental regulations, with the ability of bureaucratic structures to take up much of the change. Among expert contributions provided during the research, a common theme seems to be that with the exception of newer examples such as Japan, South Korea, and Taiwan, most Asian and African ports still operate manual systems for registration processes and are burdened with a pervasive bribery culture that prevents efficiency. Perhaps an even clearer example is the bribery dynamic over the distribution of cigarettes, referred to often as the "Marlboro Canal" in Suez Canal passages, demonstrating how bureaucracy directly inflates operational cost.

Maritime security encompasses a wide range of issues, from traditional piracy activities to modern cyber threats. Fu et al. (2010) examined the impact of maritime piracy on global economic development using the example of Somalia, revealing that the threat of piracy leads to route changes and increased insurance costs. Jiang and Lu (2020) analysed piracy incidents in Southeast Asia using Bayesian Networks and determined that factors such as ship speed and freeboard height directly affect the risk of attack. In the modern era, cyber security has also become critical with digitalisation. Peng et al. (2025), in their bibliometric analysis on maritime cyber security, highlighted that cyber attacks such as jamming and spoofing targeting ship systems are an increasing risk factor. However, the expert opinions obtained within the scope of this study bring a different perspective to the issue of security, raising suspicions that there may be a secret agreement between the armed security teams taken on board ships against piracy activities around the African continent and the pirates themselves, and drawing attention to the fact that security has become a "rent economy".

The technical and fuel management of ships is of critical importance in terms of operational sustainability. Zhou et al. (2020) evaluated hazard analysis methods such as FMEA and HAZOP for autonomous ships, highlighting the role of technical failures such as propulsion loss and sensor errors in risk analysis. Regarding fuel consumption and emission reduction, Bai et al. (2025) provided a comprehensive review of ship emission reduction technologies, highlighting the importance of alternative fuels and digital intelligence technologies. Chang and Jhang (2016) analysed the effectiveness of slow steaming strategies in ports in reducing fuel costs and emissions. Furthermore, Milewska and Milewski (2022) discussed the impact of rising fuel costs on supply chain strategies.

Within the scope of this study, experts state that different measurement units and local documentation structures used particularly in North America create complexity in standard international trade processes and declaration stages in the context of technical and documentation barriers. Additionally, it has been observed that the strict MARPOL (Marine Pollution Prevention) protocols, which are rigorously applied in the Oceania and European regions, can have a slowing effect on operational speed due to the intensive inspection processes they entail, despite serving environmental protection objectives.

The vast majority of maritime accidents are attributed to human error, with fatigue and personnel management being key issues. Akhtar and Utne (2014) modelled the effect of human fatigue on grounding accidents in maritime transport using Bayesian Networks and quantitatively demonstrated the impact of shift patterns on accident risk. Luo and Shin (2019) noted that the focus of maritime accident research over the past half-century has shifted from ship architecture to human error, emphasising the central role of the human factor in accident formation. Puisa et al. (2018) analysed that in maritime accidents, not only the ship's personnel but also the disconnections in interaction between company management and regulatory bodies (systemic factors) play a significant role. The role of the human element in the transition to autonomous ships was also examined by Mallam et al. (2019).

Weather and sea conditions directly affect navigation safety and route planning. Liu et al. (2023) analysed the restrictive effects of challenging environmental conditions, such as icing and low temperatures, on ship operations by examining ship performance and ice navigation algorithms on Arctic routes. Vettor and Guedes Soares (2016), in their study on weather routing, demonstrated the importance of strategies for avoiding storms and minimising fuel consumption. Wan et al. (2024) developed models to assess the resilience of ports to extreme weather events such as typhoons, revealing how environmental factors can disrupt port operations. Shigunov (2023) extrapolated vessel failure rates based on wave height, indicating that adverse weather conditions increase technical risks.

One of the factors most affecting global trade in recent times has been geopolitical tensions. Notteboom and Haralambides (2025) note that ports can be left vulnerable like "sitting ducks" in geopolitical conflicts and that supply chains are being reshaped in pursuit of strategic autonomy. Koray et al. (2025) examined supply chain disruptions in maritime transport, analysing the disruptive effects of geopolitical tensions, wars and pandemics on the global economy and the logistics strategies that could be developed to counter them, based on expert opinions using the AHP method. Haralambides (2024) discussed the risks at trade chokepoints using the example of the Red Sea crisis. Furthermore, Tsang et al. (2024) examined supply chain vulnerabilities in the context of the Russia-Ukraine conflict.

When the literature review is evaluated as a whole, it is seen that concepts such as port congestion, bureaucracy and security are frequently addressed at an academic level. However, this study originalises the criterion of Bureaucratic Barriers, which is generally discussed in the literature within a theoretical and managerial framework, by supporting it with field observations such as the "established culture of bribery" among captains. Similarly, the security factor, analysed in the literature as route changes and insurance costs, is re-examined in this study from the perspective of the "rent economy" between security companies and asymmetric threats, enriched by the first-hand operational insights of captains. This approach contributes to the literature by treating maritime transport risks not merely as academic variables but as concrete realities that govern the daily operations of ship captains.

2. Method

This section covers the conceptual framework of the research, data collection processes and analysis methods. The research is structured around the analysis of operational risks in maritime transport within a hierarchical structure.

2.1. Research Design

This study adopted a hybrid (mixed methods) research design that combines qualitative field findings with quantitative decision support models Such a research design integrates qualitative and quantitative approaches within a single study, providing a more comprehensive understanding of complex research problems (Creswell & Plano Clark, 2017). In the research design, a multi-criteria decision-making (MCDM) approach based on a two-stage validation process was applied to identify the fundamental problems encountered in international maritime trade and to rank the six continents other than Antarctica in terms of performance according to the specified criteria. Within the scope of the study, the risk factors identified in maritime transport were analysed based on the BWM (Rezaei, 2015) and SAW (Taherdoost, 2023) methods. Furthermore, the AHP (Saaty, 1980) and TOPSIS (Hwang & Yoon, 1981) methods were used as control mechanisms to test the reliability of the analysis results and to perform robustness checks using different mathematical approaches.

2.2. Study Group

The group of experts participating in the study consists of three senior ship captains with a cumulative total of 60 years of experience in the maritime sector. Two members of the participant group are first captains with 20 and 25 years of experience, while one member is a second captain with 15 years of experience. Although the participants have worked on different types of ships throughout their careers due to contract-based working models, they have mainly specialised in dry cargo ships. The most critical point is that all three experts have made numerous trips to all continents covered by the analysis throughout their professional careers and have personally managed operational processes in approximately 150 different international ports. This extensive geographical experience demonstrates that the judgements presented are not isolated but reflect a global projection. Consequently, the demographic and professional profile of the expert group is considered to possess the operational competence required to carry out the global continental analysis covered by the study. In MCDM-based studies requiring highly specialised expertise, relatively small expert panels are frequently considered methodologically acceptable when the participants possess substantial field experience and domain-specific operational knowledge. Beyond years of experience alone, participant selection was based on the criterion of depth of operational exposure and diversity of geographical experience. The experts included in the study had direct responsibility for navigation, port coordination, customs procedures and operational decision-making across multiple international routes. Therefore, the value of the expert panel derives not from numerical representativeness but from accumulated tacit knowledge and sustained field engagement, which are recognised as critical inputs in specialised MCDM applications. Accordingly, the study prioritised expert qualification and contextual knowledge over panel size.

2.3. Research Process

The research process was meticulously conducted in four main stages, following on from one another, from the establishment of the theoretical framework to the mathematical validation of the findings.

2.3.1. Determination of Criteria

The study criteria were established through a comprehensive literature review and focus group discussions with industry professionals. Within the above framework, face-to-face interviews were conducted with three ship captains who have substantial experience in the maritime trade of the Gölcük district of Kocaeli province.

Participants were asked to evaluate the draft criteria obtained from the literature and adapt them to align with actual operational processes. During the interviews, experts were guided to reach joint decisions based on the principle of consensus to establish the input data for the methods. During the analysis process, not only numerical data was collected, but semi-structured interviews were also conducted with experts. Concepts expressed by the experts during these interviews, which also had equivalents in the sector literature, were integrated into the findings section using content analysis methods. The criteria determined based on the data obtained and explanations of the criteria are shown in Table 1.

Table 1

Key Factors Restricting Maritime Trade Operations and Their Definitions

Symbol	Criteria	Type	Description
C1	Port Congestion	Cost	Waiting times and operational delays.
C2	Bureaucratic Barriers	Cost	Customs procedures and paperwork.
C3	Security / Piracy	Cost	Factors threatening navigational safety.
C4	Technical / Fuel Issues	Cost	Fuel supply difficulties and inadequate technical infrastructure.
C5	Personnel Issues	Cost	Crew changes and the difficulty of finding qualified personnel.
C6	Environmental Conditions	Cost	Adverse weather conditions and geographical obstacles.
C7	Geopolitical Risks	Cost	Political instability and regional conflicts.

It has been determined that the criteria addressed in the study are cost-related criteria, as they consist of negative factors that directly complicate ship operations in international maritime trade.

2.3.2. Criterion Weighting Methods

In the second stage, the BWM was applied to determine the relative importance levels of the seven criteria. The most important (Best) and least important (Worst) criteria were selected by experts, and then the other criteria were scored on a scale of 1-9 relative to these two reference points. The data obtained was optimised using a linear programming model to calculate the weight values for each criterion.

2.3.3. Performance Analysis and Ranking of Continents

In the third stage, the operational performance of the six continents (Europe, Oceania, North America, South America, Asia and Africa) was analysed using the criterion weights obtained from BWM. The SAW method was chosen for this process; the performance scores given by the experts for each continent were normalised and then multiplied by the criterion weights to create the final success indices for the continents.

2.3.4. Validation and Accuracy Analysis

In the final stage, a validation process was conducted to test the mathematical consistency and reliability of the main analysis results. Criterion weights were recalculated using the AHP and compared with the BWM results. The continental ranking was repeated using the TOPSIS method, which is based on the principle of proximity to the ideal solution. The scientific validity of the research was confirmed by the consistency ratios (CR) of the BWM and AHP methods remaining below the threshold value (0.10).

2.4. Data Collection Tools

The data was collected using the following tools to ensure qualitative and quantitative depth.

2.4.1. Semi-Structured Interview Forms

These forms have been created to take full advantage of the captains' field experience. In the interviews, concepts such as “bureaucratic obstacles” and “security risks,” which are typically abstracted in the literature, took on meaning through the “concrete” reality of the field and industry-specific language. Words such as “Marlboro Canal” (facilitation payments) and “Security Rent” (rents related to security) made these concepts concrete. The participants were asked to discuss their opinions regarding the criteria and the continents, and through the responses, the ways in which informal cost systems impeded operational flow and how regional control systems worked were qualitatively explored. The interviews were then incorporated into the findings through content analysis.

2.4.2. BWM Structured Interview Forms

During the criterion weighting process, experts were presented with "Best-to-Others" and "Others-to-Worst" comparison matrices designed in accordance with the BWM format. These tools enabled experts to score all other criteria on a scale of 1 to 9, using the specified best and worst criteria as a reference.

2.4.3. AHP Pairwise Comparison Matrices

To validate the BWM results, structured AHP pairwise comparison matrices were used. Within this scope, a total of 21 different pairwise comparison data points were collected for seven criteria, and hierarchical consistency was tested.

2.4.4. SAW and TOPSIS Performance Evaluation Tables

In the main decision matrix created to rank the performance of the continents, evaluation tables were used to enable experts to score each continent on a scale of 1 (least problem) to 10 (most problem) based on seven criteria. These tables formed the basis of the data input for both the linear normalisation process of the SAW method and the distance-to-ideal-solution calculations of the TOPSIS method.

2.5. Data Analysis

The data obtained in the research were analysed in three main stages: criterion weighting, alternative ranking and consistency analysis. Before describing the procedures for applying the quantitative methods, the rationale behind the choice of the analytical framework is outlined. The study's objective and data collection characteristics are in alignment with the BWM–SAW framework's methodology. Hence, the BWM–SAW framework was chosen as the main analytical framework of this study. BWM facilitates the assessment of criterion weights with a relatively smaller pool of pairwise comparisons, which minimizes the burden on the respondent and concerning experts. After weighting, SAW was favored due to its clear means of aggregation and ability to evaluate alternative solutions according to cost-oriented criteria. To increase methodology robustness and result stability, the BWM–SAW results were thereafter verified by the AHP–TOPSIS combination. The application procedures of the quantitative methods used in the analysis process are presented below.

2.5.1. Criterion Weighting Methods

Within the scope of the study, the BWM and AHP methods, which represent both modern and classical approaches in the MCDM literature, were used together to weight the criteria.

2.5.1.1. Best-Worst Method (BWM)

The BWM method, introduced to the literature by Rezaei (2015), was used to determine the importance levels of the criteria. BWM was preferred because it requires fewer pairwise comparisons compared to traditional methods and offers higher consistency ratios. In this method, decision-makers first identify the most important (Best) and least important (Worst) criteria, then rate the other criteria on a scale of 1 to 9 relative to these two reference points. The expert ratings obtained are optimised using a linear programming model to calculate the criterion weights (Rezaei & Davoodi, 2019).

Step 1: Decision-makers (captains) determine the most important criterion (c_B) and the least important criterion (c_W).

Step 2: The "Best-to-Others" (A_B) vector is created, comparing the best criterion (c_B) with the other criteria (j).

$$A_B = (a_{B_1}, a_{B_2}, a_{B_3}, a_{B_4}, \dots, a_{B_n}) \quad (1)$$

Step 3: The "Others-to-Worst" (A_W) vector is created, where all other criteria (j) are compared to the worst criterion (c_W).

$$A_W = (a_{1_W}, a_{2_W}, a_{3_W}, a_{4_W}, \dots, a_{n_W}) \quad (2)$$

Step 4: To find the optimum weights ($w_1^*, w_2^*, w_3^*, w_4^*, \dots, w_n^*$), the following model is solved.

$$min\ \xi^L, \qquad \left|w_B - a_{B_j} w_j\right| \le \xi^L, \ \ \forall_j, \qquad \left|w_j - a_{j_W} w_W\right| \le \xi^L, \ \ \forall_j,$$

$$\sum_{j=1}^{n} w_j = 1, \quad w_j \ge 0 \quad (3)$$

Step 5: Calculating the Consistency Ratio (CR)

The Consistency Ratio (CR) is calculated to verify the logical consistency of the weights and expert opinions obtained. At this stage, the minimum error margin (ξ^L) obtained from the optimisation model is divided by the Consistency Index (CI) value determined based on the number of criteria (n) and the scale used.

$$CR = \frac{\xi^L}{CI} \quad (4)$$

The CI values used here, as proposed by Rezaei (2015) and representing threshold values, are presented in Table 2. A calculated CR value less than 0.10 indicates that the pairwise comparisons are consistent and that the criterion weights obtained are considered reliable.

Table 2

BWM Consistency Index (CI) Table (Scale of 1-9)

n	3	4	5	6	**7**	8	9
CI	1.00	1.63	2.30	3.00	**3.73**	4.47	5.23

2.5.1.2. Analytic Hierarchy Process (AHP)

The AHP method developed by Saaty (1980) was applied to validate the BWM results. AHP is a global standard for determining hierarchical relationships between criteria and measuring consistency ratios through pairwise comparison matrices (Vaidya & Kumar, 2006).

Step 1: An ($n \times n$) pairwise comparison matrix is created. Here, a_{ij} represents the importance of criterion i relative to criterion j (on a scale of 1-9).

Step 2: The matrix is normalised and the weight vector (w_i) is calculated by taking the average of each row.

$$w_i = \frac{1}{n} \sum_{j=1}^{n} \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} \quad (5)$$

Step 3: The largest eigenvalue (λ_{max}) of the matrix is calculated.

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(A_W)_i}{w_i} \quad (6)$$

Step 4: Calculating the Consistency Ratio (CR)

The Consistency Ratio (CR) is calculated to measure the consistency of judgements in the pairwise comparison matrix. For this process, the Consistency Index (CI) is first determined using the matrix's largest eigenvalue (λ_{max}).

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (7)$$

Subsequently, the obtained CI value is divided by the Random Index (RI) value determined according to the matrix size (n) to calculate CR.

$$CR = \frac{CI}{RI} \quad (8)$$

If the calculated CR is less than 0.10, the pairwise comparison matrix is considered consistent. The AHP Random Index (RI) Table is shown in Table 3.

Table 3

AHP Random Index (RI) Table

n	3	4	5	6	**7**	8	9
RI	0.58	0.90	1.12	1.24	**1.32**	1.41	1.45

2.5.2. Alternative Ranking Methods

Using the seven identified key risk criteria, the SAW and TOPSIS methods were employed to rank the six continents outside Antarctica in terms of operational performance.

2.5.2.1. Simple Additive Weighting (SAW)

During the ranking of continents, the SAW method proposed by Churchman and Ackoff (1954) was used due to its simplicity and effectiveness. The SAW method evaluates alternatives through the weighted aggregation of normalised criterion scores (Taherdoost, 2023). Because all criteria in this research are cost-oriented operational barriers, cost-based normalisation procedures were employed throughout the analysis. In Appendix A, we can find detailed mathematical formulations concerning the normalisation as well as aggregation procedures.

2.5.2.2. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

The TOPSIS method, developed by Hwang and Yoon (1981) to validate the SAW results, was employed. TOPSIS ranks alternatives according to their relative proximity to the ideal solution and their distance from the negative ideal solution (Chen, 2000). The study used the method as a robustness-check to see whether the ranks obtained using the SAW model were stable or not. Appendix A presents in-depth mathematical procedures for normalisation, weighted distance calculations, and proximity coefficients.

2.5.3. Consistency Analysis

To prove the scientific validity of the analyses, the Consistency Ratio (CR) was calculated. For the BWM analysis, the formula $CR = \frac{\xi^L}{CI}$ shown in Equation 4 was applied, while for the AHP, the formula $CR = \frac{CI}{RI}$ shown in Equation 8 was applied. In both methods, the values obtained were below the threshold value of 0.10, proving that the data had sufficient consistency for the analysis process.

2.6. Research Ethics

The research was conducted after obtaining ethical approval from the Ethics Committee of Süleyman Demirel University, meeting number 189 and decision number 13, prior to its implementation with participants. Participants' involvement in the research was entirely voluntary. Throughout the research process, actions were taken in accordance with scientific ethical principles.

3. Findings

This study analyses the effects of seven key risk factors that constrain operational efficiency in global maritime transport and their implications in different geographical regions. The implementation process was designed within a hierarchical decision-making structure based on the expert judgements of ship captains with extensive sectoral experience. In the first stage of the analysis, the relative importance levels of the criteria were determined using the BWM method, followed by a comprehensive performance ranking for six different continents using the SAW method. Subsequently, the AHP and TOPSIS methods were used as control mechanisms to perform a robustness check on the findings obtained from the BWM-SAW model.

3.1. BWM Analysis and Findings

In this section, criteria representing seven fundamental problems encountered in international maritime transport have been weighted using the BWM method. The implementation process is based on the assessments of experienced expert ship captains in this field.

In the first step of the BWM application, decision-makers selected the criterion most affecting maritime trade operations (Best) from among seven criteria as Bureaucratic Barriers (C2) and the criteria least affecting them (Worst) as Personnel Issues (C5).

In the second step, in line with the decision-makers' views, the selected best criterion (C2) was compared with all other criteria on a scale of 1-9 to create a "Best-to-Others" table, which is shown in Table 4.

Table 4

Best-to-Others Table

Most Important Criteria:	C1	C2	C3	C4	C5	C6	C7
C2	2	1	4	7	9	5	3

The Best-to-Others vector (A_B) was created using Table 4 (Equation 1).

$A_B = (2,1,4,7,9,5,3)$

In the third step, a comparison of all other criteria with the worst criterion (C5) was made to obtain the "Others-to-Worst" table, which is presented in Table 5.

Table 5

Others-to-Worst Table

Least Important Criteria:	C1	C2	C3	C4	C5	C6	C7
C5	8	9	6	3	1	5	7

The Others-to-Worst vector (A_W) was obtained using Table 5 (Equation 2).

$A_W = (8,9,6,3,1,5,7)$

In the fourth step, the following linear programming model was established to determine the criterion weights $(w_1, w_2, w_3, w_4, w_5, w_6, w_7)$ (Equation 3). The objective of the model is to minimise the maximum absolute difference (ξ^L) between the pairwise comparisons.

$|w_2 - 2w_1| \leq \xi^L$, $|w_2 - 1w_2| \leq \xi^L$, $|w_2 - 4w_3| \leq \xi^L$, $|w_2 - 7w_4| \leq \xi^L$, $|w_2 - 9w_5| \leq \xi^L$, $|w_2 - 5w_6| \leq \xi^L$, $|w_2 - 3w_7| \leq \xi^L$,

$|w_1 - 8w_5| \leq \xi^L$, $|w_2 - 9w_5| \leq \xi^L$, $|w_3 - 6w_5| \leq \xi^L$, $|w_4 - 3w_5| \leq \xi^L$, $|w_5 - 1w_5| \leq \xi^L$, $|w_6 - 5w_5| \leq \xi^L$, $|w_7 - 7w_5| \leq \xi^L$,

$\sum_{j=1}^{7} w_j = 1, \quad w_j \geq 0,$

The final weights of the criteria (w_j^*) and the error margin (ξ^L) value, which is an indicator of consistency, resulting from the solution of the model are presented in Table 6.

Table 6

Criteria Weights and Priority Hierarchy Based on the BWM Model

Criteria	Weight (w_j^*)	Ranking
Bureaucratic Barriers (C2)	0.3542	1
Port Congestion (C1)	0.2156	2
Geopolitical Risks (C7)	0.1437	3
Security / Piracy (C3)	0.1078	4
Environmental Conditions (C6)	0.0862	5
Technical / Fuel Issues (C4)	0.0616	6
Personnel Issues (C5)	0.0308	7
Error Margin (ξ^L)	**0.0770**	

Table 6 reveals that Bureaucratic Barriers (C2) are the most dominant obstacle in international maritime trade, with a value of 0.3542. This is followed by Port Congestion (C1) with a value of 0.2156. Personnel issues (C5) were determined to be the factor with the lowest impact, at 0.0308, according to expert opinion. The consistency indicator (ξ^L) value obtained from the analysis was calculated as 0.0770. The fact that this value is very close to zero indicates that the pairwise comparisons are highly consistent. This high level of consistency stems from the fact that expert ship captains reached a consensus on the criteria during the data collection process. The fact that the expert group, with its extensive field experience, reported similar operational difficulties regarding obstacles in maritime transport has ensured the consistency of subjective judgements and reinforced the reliability of the model.

In the fifth and final step, the reliability of the analysis results was tested using the Consistency Ratio (CR) (Equation 4). As a 1-9 scale was used in this study, the Consistency Index (CI) corresponding to $n = 7$ was taken as 3.73, as shown in Table 2.

CR= 0.0770 / 3.73 = 0.0206

The calculated CR value (0.0206) is well below the generally accepted threshold value of 0.10. This result demonstrates that the assessments made by the expert are highly consistent and that the criterion weights obtained are scientifically reliable.

3.2. SAW Analysis and Findings

Using the criterion weights determined by BWM analysis, the performance ranking of alternatives (continents) was carried out using the SAW method. At this stage, all seven criteria represent issues in maritime trade and are therefore cost-related.

The initial decision matrix created based on the data obtained from the captains in the first step of the analysis is presented in Table 7. Scores range from 1 (least problem) to 10 (most problem).

Table 7

Decision Matrix Regarding the Operational Performance Scores of the Continents (x_{ij})

Continents	C1	C2	C3	C4	C5	C6	C7
Europe	1	1	1	4	1	3	1
Asia	10	9	7	6	5	8	7
Africa	7	10	10	8	10	7	9
North America	3	3	1	5	2	6	2
South America	5	7	5	5	5	4	6
Oceania	1	2	1	3	5	5	1

In the second step, the initial decision matrix shown in Table 7 was normalised (Equation 10). In the SAW method, cost-based normalisation was applied to all criteria, and the normalised decision matrix is shown in Table 8.

Table 8

Normalised Decision Matrix (r_{ij})

Continents	C1	C2	C3	C4	C5	C6	C7
Europe	1.00	1.00	1.00	0.75	1.00	1.00	1.00
Asia	0.10	0.11	0.14	0.50	0.20	0.38	0.14
Africa	0.14	0.10	0.10	0.38	0.10	0.43	0.11
North America	0.33	0.33	1.00	0.60	0.50	0.50	0.50
South America	0.20	0.14	0.20	0.60	0.20	0.75	0.17
Oceania	1.00	0.50	1.00	1.00	0.20	0.60	1.00

In the third and fourth steps, the normalised values were multiplied by the criterion weights (w_j^*) calculated using the BWM method and shown in Table 6, and the v_{ij} value was calculated (Equation 11). Subsequently, the total performance score (S_i) for each alternative was calculated using Equation 12 and presented in Table 9.

Table 9

Final Performance Index and Ranking of Continents Based on SAW Analysis Results

Alternatives (Continents)	Overall Performance Score (S_i)	Ranking
Europe	0.9845	1
Oceania	0.7637	2
North America	0.4650	3
South America	0.2470	4
Asia	0.1661	5

Africa	0.1561	6

According to Table 9, Europe has been identified as the continent with the least problems in maritime trade and the highest operational efficiency, with a value of 0.9845. It is followed in second place by Oceania, with a value of 0.7637. Asia and Africa, which have the lowest scores, stand out as regions where bureaucratic obstacles, port congestion and security risks are most keenly felt in maritime trade. The low problem scores achieved by Europe and Oceania in the criteria of Bureaucratic Barriers (C2) and Port Congestion (C1), which have the highest weighting in the BWM, are the main reason for these continents' success in the ranking.

3.3. AHP Analysis and Findings

In the study, the AHP method was applied to validate the criteria weights obtained with BWM and to evaluate them using a more comprehensive set of pairwise comparisons. Twenty-one different pairwise comparison data provided by experts were analysed. The pairwise comparisons of the criteria answered by the experts within the scope of the study are shown in Table 10.

Table 10

Pairwise Comparison Table for Criteria

Criteria	**9**	**7**	**5**	**3**	**1**	**3**	**5**	**7**	**9**	**Criteria**
Port Congestion (C1)						X				Bureaucratic Barriers (C2)
Port Congestion (C1)			X							Security/Piracy (C3)
Port Congestion (C1)		X								Technical/Fuel Issues (C4)
Port Congestion (C1)	X									Personnel Issues (C5)
Port Congestion (C1)		X								Environmental Conditions (C6)
Port Congestion (C1)				X						Geopolitical Risks (C7)
Bureaucratic Barriers (C2)			X							Security/Piracy (C3)
Bureaucratic Barriers (C2)		X								Technical/Fuel Issues (C4)
Bureaucratic Barriers (C2)	X									Personnel Issues (C5)
Bureaucratic Barriers (C2)		X								Environmental Conditions (C6)
Bureaucratic Barriers (C2)				X						Geopolitical Risks (C7)
Security/Piracy (C3)				X						Technical/Fuel Issues (C4)
Security/Piracy (C3)			X							Personnel Issues (C5)
Security/Piracy (C3)				X						Environmental Conditions (C6)
Security/Piracy (C3)						X				Geopolitical Risks (C7)
Technical/Fuel Issues (C4)				X						Personnel Issues (C5)
Technical/Fuel Issues (C4)					X					Environmental Conditions (C6)
Technical/Fuel Issues (C4)							X			Geopolitical Risks (C7)
Personnel Issues (C5)							X			Environmental Conditions (C6)
Personnel Issues (C5)								X		Geopolitical Risks (C7)
Environmental Conditions (C6)							X			Geopolitical Risks (C7)

The judgements indicated by experts with "X" marks have been converted to the 1-9 scale proposed by Saaty (1980). For example, in the comparison between Bureaucratic Barriers (C2) and Port Congestion (C1), a value of "3" in favour of C2 has been entered into the matrix, while in the comparison between C1 and C5, a value of "9" in favour of C1 has been entered. The 7 x 7 pairwise comparison matrix created in the first stage of the analysis is presented in Table 11.

Table 11

Matrix of Pairwise Comparisons of Criteria

Criteria	C1	C2	C3	C4	C5	C6	C7
C1	1	1/3	5	7	9	7	3
C2	3	1	5	7	9	7	3
C3	1/5	1/5	1	3	5	3	1/3
C4	1/7	1/7	1/3	1	3	1	1/5
C5	1/9	1/9	1/5	1/3	1	1/5	1/7
C6	1/7	1/7	1/3	1	5	1	1/5
C7	1/3	1/3	3	5	7	5	1

In the second step of the analysis, the comparison matrix was normalised and the average of each row was taken to determine the relative weights (w_i) of the criteria in the hierarchy of problems in maritime trade (Equation 5). The results obtained are shown in Table 12.

Table 12

Validating Criteria Weights Obtained Using the AHP Model

Criteria	Weight (w_i)	Ranking
Bureaucratic Barriers (C2)	0.3679	1
Port Congestion (C1)	0.2679	2
Geopolitical Risks (C7)	0.1622	3
Security / Piracy (C3)	0.0877	4
Environmental Conditions (C6)	0.0501	5
Technical / Fuel Issues (C4)	0.0427	6
Personnel Issues (C5)	0.0215	7

According to Table 12, the criteria of Bureaucratic Barriers (C2) and Port Congestion (C1) account for approximately 64% of the total criterion weight. Compared to the BWM analysis, there is a slight increase in the weight of the Geopolitical Risks (C7) criterion. This situation demonstrates that ship captains view political and strategic risks in the global context as a much more pressing threat than operational and technical problems.

In the third stage of this analysis, the largest eigenvalue of the matrix (λ_{max}) was calculated (Equation 6).

λ_{max} = 52.8385 / 7 = 7.5484

Finally, the scientific validity of the AHP method was measured using the Consistency Ratio (CR) (Equations 7 and 8). As shown in Table 3, the Random Index (RI) value for a 7-criterion matrix is 1.32.

Consistency Index (CI): (7.5484 - 7) / (7 - 1) = 0.0914

Consistency Ratio (CR): 0.0914 / 1.32 = 0.0692

The calculated CR value (0.0692) is below the generally accepted threshold value of 0.10 in the literature. This confirms that the expert judgements are logically consistent and that the weights obtained can be used in strategic decision-making processes.

3.4. TOPSIS Analysis and Findings

In this section, it has been attempted to find out the major hurdles faced in international trade through maritime transport on a continental scale using the TOPSIS method. The main idea behind doing this is to check how accurately the results obtained from the primary method hold in the case of the continental scale and how these results are affected by modifications in the mathematical model. This method provides more comprehensive and rational results for evaluating options by checking the robustness of SAW.

In the first step of the TOPSIS method, the same initial decision matrix used in SAW (available in Table 7) was used. In the next step of the TOPSIS method, the same data set was normalized using Equation 13 and the normalized decision matrix (r_{ij}) available in Table 13 was obtained.

Table 13

Normalised Decision Matrix

Continents	C1	C2	C3	C4	C5	C6	C7
Europe	0.073521	0.064018	0.075165	0.302372	0.074536	0.212664	0.076249
Asia	0.735215	0.576166	0.526152	0.453557	0.372678	0.567105	0.533745
Africa	0.514650	0.640184	0.751646	0.604743	0.745356	0.496217	0.686244
North America	0.220564	0.192055	0.075165	0.377964	0.149071	0.425329	0.152499
South America	0.367607	0.448129	0.375823	0.377964	0.372678	0.283552	0.457496
Oceania	0.073521	0.128037	0.075165	0.226779	0.372678	0.354441	0.076249

In the third step, each value was multiplied by the weight of the relevant criterion to obtain the weighted normalised decision matrix (v_{ij}), which is presented in Table 14 (Equation 14). The values considered as criterion weights (w_i) in this analysis are those obtained from the AHP method and are shown in Table 12.

Table 14

Weighted Normalised Decision Matrix

Continents	C1	C2	C3	C4	C5	C6	C7
Europe	0.019696	0.023552	0.006592	0.012911	0.001603	0.010654	0.012368
Asia	0.196964	0.211971	0.046144	0.019367	0.008013	0.028412	0.086573
Africa	0.137875	0.235524	0.065919	0.025823	0.016025	0.024860	0.111309
North America	0.059089	0.070657	0.006592	0.016139	0.003205	0.021309	0.024735
South America	0.098482	0.164867	0.032960	0.016139	0.008013	0.014206	0.074206
Oceania	0.019696	0.047105	0.006592	0.009683	0.008013	0.017757	0.012368

In the fourth step, the Positive Ideal Solution (A^+) and Negative Ideal Solution (A^-) points were determined and are shown in Table 15.

Table 15

Negative and Positive Ideal Solution Points of the Criteria

	C1	C2	C3	C4	C5	C6	C7
A^-	0.019696	0.023552	0.006592	0.009683	0.001603	0.010654	0.012368
A^+	0.196964	0.235524	0.065919	0.025823	0.016025	0.028412	0.111309

In the final stage of the study, the distances of each continent from the ideal and negative ideal points (S_i^+ and S_i^-) were calculated using Equations 15 and 16. Subsequently, the relative proximity (C_i) values representing the final success score were obtained using Equation 17. A value of C_i, close to 1 indicates that the relevant continent is in the most "ideal" position in terms of barriers to maritime trade. The results obtained from the analysis are shown in Table 16.

Table 16

Continental Performance Ranking Based on Proximity to the Ideal Solution

Alternatives	S_i^+ (Ideal Distance)	S_i^- (Negative Distance)	C_i (Success Score)	Ranking
Europe	0.3006	0.0032	0.9894	**1**
Oceania	0.2840	0.0254	0.9179	**2**
North America	0.2398	0.0639	0.7896	**3**
South America	0.1323	0.1755	0.4299	**4**
Africa	0.0592	0.2700	0.1798	**5**
Asia	0.0408	0.2728	0.1300	**6**

The results of the TOPSIS analysis indicate Europe’s leading position in maritime trade in terms of operational efficiency and low risk levels. Europe’s success stems primarily from minimised problem scores in the criteria with the highest weighting: Bureaucratic Barriers (C2) and Port Congestion (C1). In contrast, Asia and Africa have been identified as the alternatives furthest from the ideal solution, i.e. closest to the negative ideal. The main reason for Asia’s low score is the critical level of its port congestion score (10 points). Africa, meanwhile, is the second most disadvantaged region for maritime trade due to high risk scores in areas such as bureaucratic barriers and staffing issues.

3.5. Comparative Analysis and Testing the Robustness of the Model

In this section, the findings obtained from the BWM-SAW model, which was determined as the main analysis method, were compared with the results of the AHP-TOPSIS model applied for control and verification purposes, and the robustness of the obtained rankings was tested.

3.5.1. Comparison of Criteria Weighting Methods (BWM and AHP)

The results of two different weighting methods used to determine the importance levels of the criteria are presented side by side in Table 17.

Table 17

Comparative Analysis of Weights Obtained from BWM and AHP Methods

Symbol	Criteria	BWM Weight (w_j)	AHP Weight (w_i)	Ranking Difference
C2	Bureaucratic Barriers	0.3542	0.3679	Same
C1	Port Congestion	0.2156	0.2679	Same
C7	Geopolitical Risks	0.1437	0.1622	Same

C3	Security/Piracy	0.1078	0.0877	Same
C6	Environmental Conditions	0.0862	0.0501	Same
C4	Technical/Fuel Issues	0.0616	0.0427	Same
C5	Personnel Issues	0.0308	0.0215	Same

According to Table 17;

- Both methods have determined the order of importance of the seven criteria in exactly the same way.
- In both analyses, the criteria of Bureaucratic Barriers and Port Congestion accounted for more than half of the total weight, proving that they are the most critical obstacles in maritime trade.
- In the AHP analysis, the weight of Geopolitical Risks has increased somewhat compared to the BWM. This situation demonstrates that the broader set of pairwise comparisons offered by the AHP reflects the importance captains attach to strategic risks in greater detail.

When examining the criterion weights obtained in both methods, it is observed that the weights of Bureaucratic Barriers (C2) and Port Congestion (C1) account for more than half of the total effect. These findings demonstrate that the choke points in the modern system are institutional and infrastructural, like the operation of ports and customs, and not the technological limitations of the ships themselves. In addition, note that Personnel Issues (C5) having the lowest priority means that the level of maturity of automation and training of crew has reached a good level, but administrative issues still pose enormous unmanaged risks.

Moreover, a comparison of the consistency ratios (CR) of BWM and AHP shows that BWM has a higher consistency with a CR of 0.0206 compared to that of AHP, which is 0.0692. This is attributed to the fact that BWM necessitates a relatively small number of pairwise comparisons, given by 2n - 3, compared to the relatively large number of pairwise comparisons, given by n(n - 1)/2, in the AHP. As emphasized in the literature (Rezaei, 2015), a decrease in the number of pairwise comparisons reduces the cognitive load of the decision-maker’s and minimizes any systematic errors (biases) in the decision-maker’s judgment. Although achieving full consistency of the matrix becomes more challenging with an increase in the number of criteria in the AHP, BWM yields more refined and consistent weight vectors. This is attributed to a more focused data collection process, where only the best and worst criteria are considered. The low CR supports the internal validity of the models used in this research. It is a reflection of the reliability of expert judgments from a methodological point of view.

3.5.2. Comparison of Alternative Ranking Methods (SAW and TOPSIS)

The continent rankings obtained using the SAW and TOPSIS methods, which have different mathematical foundations, are compared in Table 18.

Table 18

Ranking Correlation and Robustness Test Between SAW and TOPSIS Models

Alternatives	SAW Score (S_i)	SAW Ranking	TOPSIS Score (C_i)	TOPSIS Ranking
Europe	0.9845	1	0.9894	1
Oceania	0.7637	2	0.9179	2
North America	0.4650	3	0.7896	3
South America	0.2470	4	0.4299	4
Africa	0.1561	6	0.1798	5

Asia	0.1661	5	0.1300	6

Upon careful examination of Table 18;

- In both methods, Europe has maintained its leadership as the continent with the fewest problems in maritime trade and the highest efficiency.
- In the SAW analysis, Asia ranks fifth and Africa sixth, whereas in the TOPSIS analysis, these two continents switch places, with Asia falling to last place.
- The fundamental reason for Asia's ranking at the bottom in TOPSIS is that the highest problem score this continent received in the Port Congestion (C1) criterion more sharply increased the distance from the ideal solution. The TOPSIS method, based on the "Distance from Ideal" logic, has reflected Asia's critical disadvantage more prominently in the ranking.

The ranking variation of Asia and Africa should not be construed as a methodological inconsistency of the SAW and TOPSIS model. The primary difference between the two methods arises because of their different maths. As SAW method applies the additive aggregation of weighted scores of all criterion available with it the TOPSIS method is relatively more sensitive to extreme values since it ranks the evaluated alternatives according to their relative distance from both the ideal and the negative ideal solutions. In this regard, Asia's higher score in the critical Port Congestion criterion (C1) increases its distance from the ideal more severely in the TOPSIS model, resulting in it being ranked lower than Africa, despite generally similar continental performance patterns.

In the performance assessment of continents, both methods (SAW and TOPSIS) gave a high correlation. In both analytical perspectives, Europe emerged as the region demonstrating the highest operational efficiency and the lowest level of maritime trade barriers across both analytical approaches. Conversely, Asia and Africa had high scores for bureaucracy and port traffic. For this reason, they are confirmed to be the regions with the highest risk for maritime transport. Last in both analyses. Asia was ranked the lowest in the TOPSIS analysis. This result is due to the method's ability to identify the deviation of a choice from the ideal solution more sensitively. Also, 10 point extreme values were applied to the region to assess port congestion.

3.5.3. Methodological Validation and Overall Assessment

The high consistency between the main analysis (BWM-SAW) and the validation analysis (AHP-TOPSIS) applied in the study supports the stability of the findings and their independence from the mathematical model selection.

- The consistency ratios in both the BWM (CR=0.0206) and AHP (CR=0.0692) analyses remaining below the 0.10 threshold value indicates that the expert captain opinions are methodologically consistent and sufficiently reliable for analytical evaluation.
- The fact that the overall ranking of the continents, particularly the top four, remains unaffected by the change in methodology demonstrates that the study's findings are based on solid foundations independent of the choice of mathematical model.

Consequently, the findings obtained from both methods suggest that decision-makers seeking to improve maritime transport operations should prioritise low-bureaucracy governance approaches and effective port management practices observed in the European and Oceania models.

4. Conclusion, Discussion and Recommendations

Using comparative decision-making models, a global performance measure has been implemented through the analysis of seven risk factors that threaten to impact the operational efficiency and safety of international maritime transport. The findings imply that institutional and administrative procedures are more salient with operational efficiency as compared to solely ship-related technical criteria. This explanation lends credence to earlier research on the significance of the quality of governance and procedural efficiency in maritime logistics. As indicated by Munim & Schramm, the administrative processes are particularly noteworthy of logistics performance. Field-based observations obtained from expert interviews also support the findings of the study from an operational perspective. Experts have pointed out that not only are legal documents part of the bureaucratic burden in logistics activities; non-procedural payments, known in the sector as the “Marlboro Canal,” are used for the smooth operation of activities, especially in strategic points of transit like the Suez Canal. The findings obtained in this study show parallels with the observations reported by Markkula (2022), who discussed the presence of informal facilitation practices and transaction-related frictions in maritime transit environments. This barrier, identified in the literature as managerial efficiency, is derived from specific barriers identified in the field and clarified in this study through quantitative representation of relevant realities.

The findings further underline the importance of operational bottlenecks and governance-related delays in global supply chain continuity. The increased emphasis on this criterion corroborates the cost-centric approach adopted in the studies by Bai et al. (2022b) and Nektarios and Konstantinos (2025). However, the captain surveys also indicate that congestion does not necessarily arise from the lack of physical infrastructure at the ports. Notably, in South American ports such as those in Colombia, it was observed that the stringent security protocols aimed at curbing the flow of drugs, as well as the comprehensive inspection of vessels, including deck, hold, and under-deck inspections, which continue at ports of call even after the vessel has left the port, artificially slow down trade movements. The relationship between the "Geopolitical Risks" and "Security" criteria can also be demonstrated by the activities of pirates operating in the waters around West Africa. Experts participating in the study described a perceived cycle of cost generation associated with private maritime protection practices in piracy-prone regions and referred to this phenomenon as “security rent”. This terminology emerged directly from practitioner narratives collected during face-to-face interviews and is not presented as an established theoretical concept. Rather, it is used descriptively to illustrate how security-related operational costs may be perceived by maritime practitioners as shaping operational decision environments.

The research has some limitations, although the results are consistent in methodology. According to the assessments of three professional ship captains, the results depend on expert judgement and industry-specific operational experiences. Despite the fact that the selected respondents had extensive international maritime expertise with deep operational exposure to a number of maritime environments, the generalisability of the findings may be fortified by deploying larger and more diverse expert groups in future studies including port authorities, logistics managers and maritime security experts. In addition to these sample-related limitations, the study’s continental-level evaluation should be interpreted with caution for heterogeneous regions such as Asia and Africa, both geographically and economically. There are significant differences in the quality of port infrastructure, technological development, administrative efficiency and operational capacity of countries and ports found in these continents. For example, Singapore differs vastly from the port systems of developing countries in the aspect of logistics integration and institutional efficiency. Therefore, the continental aggregation used in this study represents a macro-level analytical framework rather than a homogeneous regional performance structure. Future studies may provide more detailed insights through country-based or port-specific comparative analyses.

Methodologically, the combined use of the BWM and AHP methods has increased the robustness of the results. As emphasized by Rezaei (2015), BWM requires fewer pairwise comparisons and provides more consistent results. In this study, the fact that the BWM consistency ratio is significantly lower than the AHP ratio validates this claim of methodological superiority in the context of maritime operations.

In the continent-based performance evaluation, SAW and TOPSIS analyses yielded consistent results, indicating that Europe is the most successful region in maritime trade, while Asia and Africa are the most disadvantaged. This ranking is largely consistent with the World Bank LPI data as well as the governance analyses conducted by Monios and Wilmsmeier (2022). While Europe and Oceania's success is based on digitalisation and procedural transparency, captains have noted that strict environmental protocols such as the International Convention for the Prevention of Pollution from Ships (MARPOL) in these regions sometimes slow down operational speed to a challenging level. In North America, rather than an inertia type of bureaucratic logic, it has been identified that using different measurement units and documentation structures of the global system is a structural barrier. As per sources, the continued heavy use of manual record-keeping systems, particularly in Africa and in Asian countries like India, Thailand and Bangladesh, is largely responsible for the low ranking of the two continents, and the resultant lack of transparency gives rise to vulnerabilities related to procedural transparency and other informal practices.

On the basis of these broad findings, measures have been taken to enhance global maritime trading. The first important step is to get "Single Window" digital declaration systems certified by the International Maritime Organisation (IMO) for more widespread deployment that reduces human involvement and increases chances of bribery in ports of Asia and Africa. Apart from that, customs clearance procedures should be standardised through internationally integrated digital documentation systems to diminish procedural delays from disjointed administrative practices. Port authorities should also broaden the scope of blockchain-based cargo tracking and automated verification systems to mitigate discretionary intervention and enhance procedural transparency. International auditing mechanisms coordinated by the IMO and WCO that occur periodically might help to mitigate instances of informal transactions while strengthening institutional accountability in high-risk maritime regions. Monitoring by independent international organizations of private security firms should be there. The piracy risk should not be turned into an opportunity for economic and commercial activities. Invest in smart scanners, including artificial intelligence-based risk analysis and underwater drone capabilities, to ensure that legitimate security concerns like drug searches in South American ports do not impede the flow of trade.

To sum up, the present study demonstrates that the risks of maritime transport are not only of a technical nature but also of an administrative transparency and digital transformation character, equally as important as the vessel's technical equipment. Incompatibilities of a technical nature, like the use of measurement units in North America, can be overcome through logistical diplomacy to reduce the region-specific differences in vessel performance, while the procedural excellence of Europe can be considered a benchmark in the development of port infrastructure. In the course of further research, the use of dynamic simulation models to analyze the direct effects of geopolitical crises, including all stakeholders like port authorities and shipowners, promises a more complete view of how to tackle the problems.

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Appendix A. Standard Mathematical Formulations Used in SAW and TOPSIS Methods

This appendix presents the standard mathematical formulations used in the SAW and TOPSIS methods that were transferred from the main methodology section in order to improve readability and maintain a more focused presentation structure.

A.1. Simple Additive Weighting (SAW)

Step 1: An initial decision matrix (x_{ij}) is created based on expert opinions.

Step 2: The initial decision matrix is normalised.

For benefit-oriented criteria:

$$r_{ij} = \frac{x_{ij}}{max_i(x_{ij})} \tag{9}$$

For cost-related criteria:

$$r_{ij} = \frac{min_i(x_{ij})}{x_{ij}} \tag{10}$$

Step 3: The weighted normalised decision matrix (v_{ij}) is created. The w_j value used here represents the previously calculated criterion weights.

$$v_{ij} = w_j r_{ij} \tag{11}$$

Step 4: The total performance score (S_i) is calculated for each continent.

$$S_i = \sum_{j=1}^{n} w_j \, r_{ij} \tag{12}$$

Here, the continent with the highest S_i value is ranked as the most successful alternative.

A.2. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

Step 1: The initial decision matrix (x_{ij}) is created.

Step 2: The normalised decision matrix (r_{ij}) is created. Since all criteria in this study are cost-related, the following equation is used.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{13}$$

Step 3: The weighted normalised decision matrix (v_{ij}) is created. The w_i value used here represents the previously calculated criterion weights.

$$v_{ij} = w_i r_{ij} \tag{14}$$

Step 4: The Positive Ideal Solution (A^+) and Negative Ideal Solution (A^-) points are determined.

Step 5: The Euclidean distances (S_i^+, S_i^-) of each alternative to these ideal points are calculated.

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \tag{15}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \tag{16}$$

Step 6: The proximity coefficient to the ideal solution (C_i) is calculated.

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-} \tag{17}$$

The continent with the C_i value closest to one ranks first.