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Strategic Management Modeling for Offshore Tugboat and Support Vessel Operations: A Hybrid SWOT-TOWS Fuzzy DEMATEL-TOPSIS Framework

Ali Burçin Eke[1], Ozan Batmaz[2], Muhammed Fatih Gülen[1], Esma Uflaz[1], Özcan Arslan[1]

[1]İstanbul Technical University Faculty of Maritime, Department of Maritime Transportation and Management Engineering, İstanbul, Türkiye
[2]Dokuz Eylül University Faculty of Maritime, Department of Maritime Transportation and Management Engineering, İzmir, Türkiye

Abstract

The maritime sector, particularly in offshore tugboat and support vessel operations, faces multifaceted strategic management challenges due to rapid technological advancements, environmental regulations, and market conditions. This paper introduces an innovative strategic decision-making framework for this industry, integrating Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis with Fuzzy Decision Making Trial and Evaluation Laboratory-*DEMATEL* and Order of Preference by Similarity to Ideal Solution-*TOPSIS* methodologies. A thorough extensive literature review and expert contributions identified 20 key factors impacting the sector across 4 SWOT categories, with balanced weights of 25.14% (strengths), 25.32% (weaknesses), 24.68% (opportunities), and 24.86% (threats). The hybrid approach uniquely highlights the interdependencies among these factors, offering a prioritized list of 8 strategic options. The analysis revealed that the WO1 strategy (focusing on cost reduction through technological innovation) emerged as the most effective strategy with a closeness coefficient of 0.798, followed by SO2 (operational efficiency enhancement) at 0.642, and ST1 (leveraging experienced crew and advanced technology) at 0.550. These results show that operational cost reduction through technological innovation and emerging market entry is a strategic priority. This study contributes significantly to the existing literature by providing a robust strategic management model tailored to address the unique challenges of offshore maritime operations. These insights are useful for improving operational efficiency for industrialists with sustainability-related concerns and for furthering their competitive advantage in an increasingly dynamic global environment. Moreover, the study also provides a replicable model that can be applied to other industries where similarly complex decisions can be made.

Keywords: SWOT, TOWS fuzzy DEMATEL, TOPSIS, Strategic management, Offshore tugboat and support vessel operations

1. Introduction

Sea trade has also, for a very long time, played the role of a building block in shaping trade, travel, and transportation among people. One of the defining attributes of this great industry is its towage services [1]. A tugboat can be described as a handy vessel built to pull or push other vessels through harbors, coastal areas and rivers [2]. In particular, tugboats are responsible for ensuring the safety and efficiency of congested ports and narrow channels during ships' movements [3]. With the increasing volumes of global maritime trade, the volume of work also increases for each port, which serves to connect land transport with that of the

Address for Correspondence: Esma Uflaz, İstanbul Technical University Faculty of Maritime, Department of Maritime Transportation and Management Engineering, İstanbul, Türkiye
E-mail: uflaz16@itu.edu.tr
ORCID iD: orcid.org/0000-0003-2229-8242

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sea. Tugboats, as essential port services, support vessels by escorting, towing, berthing, and departure, especially in congested narrow waterways where maneuverability is impeded. Without the assistance of tugboats, large vessels risk losing control. This can lead to collisions with nearby vessels, docks, and other port facilities. Therefore, tugboat operations are crucial for the safe and efficient management of ports [4].

Climate change is among the global problems that humanity is currently facing. The port industry by its nature related to international trade, contributes to greenhouse gas emissions through the operational functions of tugboats. These emissions raise environmental and health hazards, particularly in highly populated ports, and are one of the causes of climate change. Environmental measures such as switching to cleaner and more renewable energy sources are therefore being sought by port authorities and tugboat operators [5]. Technological changes characterize modern-day towage services. The invention of modern tugboats operating in traditional and hazardous waters has improved the safety and efficiency of the maritime industry [1]. Although emission control technologies are widely applied to ships, very few are applied to tugboats [6]. This means that the development of transport systems, including maritime transport, needs to be directed toward alternative low-carbon fuels, like Liquified Natural Gas (LNG) and hydrogen [7]. Today, LNG has gained popularity in the maritime industry because of its cleaner energy benefits. It helps reduce harmful emissions like nitrogen oxides, sulfur dioxide, and particulate matter. This, in turn, improves the air quality in ports [8]. Most fuel-powered tugboats emit substances into the atmosphere, which are related to environmental concerns in the maritime field. More eco-friendly technologies, such as electric tugboats, are therefore being increasingly used to address these issues. Electric tugboats greatly minimize harmful emissions and further improve air quality and environmental sustainability, mainly at busy ports [9].

Tugboats, with their high engine power, consume a great deal of fuel and emit huge emissions [10]. Reducing environmental impact and ensuring operational efficiency have gained much importance in the shipping industry. The utilization of hybrid power systems in tugboats is considered beneficial due to several factors, including emission reduction, fuel economy, cost-saving on maintenance, and workplace health improvement [11]. These hybrid systems contribute a great deal to the environment in that they show considerable improvements in terms of emissions when using normal conventional fuels, hence ensuring better air quality. They also reduce operating costs by improving fuel economy and lowering maintenance requirements. As a result, their operational efficiency is enhanced. For instance, the tugboat Carolyn Dorothy is based on an award-winning dolphin series by Robert Allan Ltd. for its prime power and positioning in restricted waterways. Wider adoption of hybrid propulsion systems can improve the shipping industry's efficiencies with fewer environmental impacts [11].

This research attempts to fill this critical gap in the existing literature by presenting an integrated strategic management framework, specifically designed for offshore tugboat and support vessel operations. Therefore, the major objectives of this study are to identify and prioritize key factors affecting the industry, to analyze their complex relationships, and to prioritize strategic options according to their impact magnitudes. The present study exploits the complementarity of Strengths, Weaknesses, Opportunities, and Threats-Threat, Opportunity, Weakness and Strength (SWOT-TOWS) analysis, Fuzzy Fuzzy Decision Making Trial and Evaluation Laboratory (DEMATEL), and Order of Preference by Similarity to Ideal Solution (TOPSIS) for new synthesis; it therefore provides an in-depth and detailed strategic landscape. Thus, it would help the sector address its issues, such as operational efficiency, cost reduction, improved profitability, and environmental concerns. This study contributes to strategic management literature by providing a strong and quantitative decision-making (DM) framework tailored to the peculiarities of maritime operations. From an industrial practitioner's perspective, it is a useful tool in making difficult strategic choices and setting higher benchmarks with respect to operational and environmental performance. The remainder of this paper is structured as follows: Section 2 reviews the related literature; Section 3 outlines the methodology, and Section 4 presents the findings and discussion. The conclusions and suggestions for future research are presented in Section 5.

2. Literature Review

Strategic management businesses first explore changes in the environment and opportunities, along with risks from competition. This step then completes an in-depth analysis of the competitive environment concerning industrial characteristics, competitor activities, and consumer behavior and preferences. Furthermore, they evaluate their resources and capabilities in terms of strengths and weaknesses to meet strategic goals. Based on this, corporations devise special value propositions to retain customer loyalty and generate a sustainable competitive advantage. Strategic management also strives to design policies and methods to improve efficacy, reduce costs, and streamline operations. Together, these interconnected elements constitute the cornerstone of the strategic management process, facilitating businesses in attaining and retaining competitive advantage [12].

Kuzu [13] explored the application of the Fuzzy DEMATEL method to understand and resolve issues in shipbuilding and structural research. Shi et al. [14] developed a quantitative risk analysis approach using complex networks and DEMATEL to manage ship collision risks, identifying 46 risk-influencing factors (RIFs) and highlighting 10 key RIFs from a global network perspective and 11 from a causality perspective. Liu et al. [15] examined the maritime supply chain's resilience post-coronavirus disease-2019 using Analytic Hierarchy Process-Quality Function Deployment-DEMATEL (AHP-QFD-DEMATEL) to analyze critical resilience factors. Torkayesh et al. [16] proposed an extended DEMATEL method with type-2 neutrosophic numbers and K-means to identify barriers to renewable fuels in Germany's transportation sector. Umut [17] used DEMATEL to evaluate factors causing navigation equipment failures and recommended preventive measures. Guan et al. [18] used Fuzzy DEMATEL to assess barriers to blockchain adoption in port logistics, identifying cause-effect relationships among barriers. Ayaz et al. [19] identified barriers to integrating ports into eco-friendly systems using Fuzzy DEMATEL, highlighting long payback periods and high investment costs as key triggers. Özdemir and Güneroglu [20] employed DEMATEL and Analytic Network Process (ANP) to evaluate human factors in maritime accidents. Durán et al. [21] analyzed strategic synergy within port communities using DEMATEL, emphasizing technological integration and coordination among port actors. Lin [22] developed a new methodology using Balanced Scorecard, DEMATEL, and ANP for risk analysis in maritime accidents. Chen et al. [23] proposed a model for vulnerability assessment based on DEMATEL, Interpretive Structural Modeling, and AHP-entropic weight method in the context of the maritime transportation system. Sun et al. [24] integrated QFD, Multiple Criteria Decision Making (MCDM), and Intuitionistic Fuzzy Sets with DEMATEL to tackle uncertainty and complexity in the bauxite maritime supply chain. Muravev et al. [25] indicated several issues regarding the China Railway Express and proposed the DEMATEL-Multi Atributive Ideal-Real Comparative Analysis for optimizing the locations of international logistics centers. Hossain et al. [26] used SWOT analysis regarding shipbuilding companies in China in view of the shifting trends of the shipbuilding industry to Asia, based on global economic conditions and trends in shipbuilding orders.

Cheng and Ouyang [27] combined decision matrix and SWOT analyses to develop strategic policies for unmanned autonomous ships, marking a novel approach in this area. Tseng and Pilcher [28] analyzed, from a corporate perspective, the business potential of the Kra Canal using a combined Political, Economic, Societal, Technological, Environmental, Legal and Ethical and SWOT analysis for companies, ports and countries. Vorkapić et al. [29] proposed a framework for shipboard energy efficiency monitoring while systematically observing internal and external environments and using SWOT to spot strengths, weaknesses, opportunities, and threats. Bauk [30] analyzed the performance of unmanned aerial and underwater vehicles for maritime surveillance, employing SWOT to position these technologies effectively. Aleksanyan [31] conducted a SWOT analysis of autonomous navigation systems based on expert opinions and the influence of reduced crews associated with increased automation. Serra et al. [32] used SWOT analysis and described how blockchain technology affects port and general maritime digitalization, pointing to practical applications and barriers. Papaioannou et al. [33] evaluated the potential of Mobility as a Service in passenger transport, focusing on coastal shipping in Greece's Aegean Islands, through expert interviews and SWOT analysis. Kelfaoui et al. [34] applied SWOT analysis to revitalize rural tourism in Algeria's Great Kabylie community, leveraging a combination of literature review, field research, and analytical approaches. Mafrisal et al. [35] assessed the potential of marine resources to enhance community welfare in Indonesia's Makassar archipelago using integrated planning and SWOT analysis. Oral and Paker [36] identified and prioritized security risks in container shipping between Turkey and the Far East, employing the Delphi technique and SWOT analysis. Palmén et al. [37] evaluated energy sources for an Arctic research icebreaker by conducting a SWOT analysis on fuel options, infrastructure suitability, and operational resilience, followed by a comprehensive assessment of fuel tank space, lifetime costs, and CO_2 emissions. Kizielewicz and Sałabun [38] investigated the impact of using information-based methods, such as entropy and standard deviation, for re-identifying criterion weights in multi-criterion decision analysis when expert input was limited. Gazi et al. [39] identified key criteria for women's empowerment in sports by employing literature review, expert opinions, and direct interactions with sector professionals and applied the DEMATEL method with pentagonal fuzzy sets to address uncertainties, thereby providing strategic decision support. Elraaid et al. [40] explored the development of construction projects in Libya's Misrata Free Zone, addressing the challenges encountered and utilizing the AHP to identify the role of the Project Management Office in overcoming these obstacles and developing strategic solutions. Kannan et al. [41] developed the Linear Diophantine Fuzzy Set as an extension to traditional fuzzy sets to address uncertainty in human DM and integrated it with the Combinative Distance-based Assessment method, proposing a novel approach for solving complex DM problems characterized by uncertainty and imprecision.

The existing literature offers significant insights into various dimensions of strategic management, technological advancements, and environmental challenges within the offshore tugboat and support vessel industry. Nevertheless, a critical gap persists in the integration of these diverse elements into a holistic strategic management framework specifically designed for the maritime sector. While individual studies have separately applied SWOT analysis, Fuzzy DEMATEL, and TOPSIS within maritime contexts, the combined and synergistic use of these methodologies to address the complex challenges in offshore support vessel operations remains underexplored. It is also an industry that is dynamic, where continuous change due to technological innovation, strict environmental legislation, and changes in market conditions require a more sophisticated and agile approach to strategic DM. This study aims to fill these gaps by designing an integrated framework that not only highlights and prioritizes strategic factors but also focuses on their complex interrelationships and provides a quantitative basis for the selection of strategies. The basis of this research is embedded in the theoretical discourse on strategic management in specialized maritime operations, while providing relevant tools for industry practitioners to effectively address the complications of their operational environment. The methodology used and findings that directly address these identified gaps are discussed in the following sections, along with specific details.

3. Methodology

Most strategic management of offshore tugboats and their support vessels is complex in nature and requires a multifaceted analytical approach. In this respect, the research incorporates SWOT-TOWS analysis, Fuzzy DEMATEL, and TOPSIS to provide in-depth analyses of internal and external factors, the interrelations among these factors, and the determination of priorities in strategic alternatives.

3.1. SWOT-TOWS Analysis

SWOT analysis includes four factors: strengths, weaknesses, opportunities, and threats. The strengths and weaknesses are internal factors, and opportunities and threats are external environmental factors. The SWOT is illustrated as a four-quadrant matrix that categorizes and summarizes these factors for quick comprehension [42]. SWOT analysis examines internal strengths and weaknesses, as well as external opportunities and threats. This analysis aims to leverage strengths, minimize weaknesses, maximize opportunities, and overcome threats [43].

The advantages of SWOT analysis are its simplicity and ease of understanding. It can be used at more than one level within an organization, and the depth can range from a quick assessment to an in-depth analysis. In addition, it links well with corporate objectives and strategies, and the format is visual, facilitating communication. However, SWOT has notable disadvantages. It often relies on qualitative and subjective data, leading to broad generalizations. The process is susceptible to biases and can confuse data collection and DM. Misapplication is common, especially when fundamental principles and methods are ignored, sometimes resulting in it being considered a significant time-consuming task if not properly facilitated [44]. In particular, when developing alternative strategies based on SWOT analysis, the TOWS matrix is an invaluable tool. As presented by Ghazinoory et al. [45] and shown in Table 1, the TOWS matrix aids in formulating effective strategies by systematically examining SWOT-identified factors. This framework facilitates the creation of effective strategies by systematically assessing the factors identified through SWOT analysis. Specifically, Strengths and Opportunities (SO) strategies are designed to leverage organizational strengths to capitalize on available opportunities. Weaknesses and Opportunities (WO) strategies leverage opportunities to address various weaknesses, preventing potential weaknesses from becoming actual challenges. Strengths and Threats (ST) strategies utilize strengths to overcome or avoid threats, ensuring the organization remains resilient in hostile and adverse environments. Finally, Weaknesses and Threats (WT) strategies call for exploiting defensive measures with respect to both weaknesses and external threats to reduce the risks from such combined threats. This approach promotes a structured methodology for strategic planning that is both adaptive and proactive. This ensures that all critical aspects are considered, providing a comprehensive framework for effective DM [45].

3.2. Fuzzy-DEMATEL

DEMATEL was developed in 1973 by Gabus and Fontela [46] as an MCDM technique. Similar to other MCDM methods, DEMATEL analyses expert opinions and solves DM problems. DEMATEL will be able to measure the weights of the relationships among criteria, considering cause-and-effect relationships among the complex and multiple criteria. DEMATEL is applied in group decisions, such as finding the critical factors influencing the systems of disaster operations management, hospital service quality, industrial symbiosis networks, sustainable supply chains, emergency management, supplier and truck selection, and electric vehicle [47]. The fuzzy DEMATEL method was

Table 1. *TOWS matrix*

Objectives	Strengths (S)	Weaknesses (W)
Opportunities (O)	SO Strategies	WO Strategies
Threats (T)	ST Strategies	WT Strategies
TOWS: Threat, Opportunity, Weakness and Strength		

applied to analyze the complex interrelationships among the SWOT factors. The fuzzy logic was implemented to bear with the uncertainty and subjectivity that would arise in expert judgments.

3.3. TOPSIS

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is a multi-criteria DM method that evaluates alternatives based on their proximity to an ideal solution. The ideal solution represents the best possible values for each criterion, while the anti-ideal solution reflects the worst. TOPSIS selects the alternative that minimizes the geometric distance from the ideal solution and maximizes the distance from the anti-ideal solution. One of the primary advantages of TOPSIS is its ability to reduce subjectivity, confining it mostly relies on assigning weights to criteria. This method is also considered to be logically sound because it coincides with rational choice and has the advantage of computational simplicity and ease of implementation. Therefore, it is practical for real applications. The results of TOPSIS can be represented graphically, especially for lower dimensions, which improves interpretability. However, TOPSIS has some limitations, challenges in calculating criteria weights and ensuring decision consistency. Whatever the difficulties related to such issues may imply, TOPSIS's efficiency regarding the complexity-usability trade-off placed it among the most frequently used techniques in multi-criteria decision analysis [48].

3.4. Integrated Methodology

This section describes the integration of SWOT-TOWS based fuzzy-DEMATEL and TOPSIS methodologies. The framework of the integrated methodology is presented in Figure 1.

The integration of these methods provides a comprehensive framework for strategic DM. The SWOT analysis provides the foundational factors, and the TOWS matrix enables the identification of initial strategies. The Fuzzy DEMATEL analysis then offers insights into the complex interrelationships among these factors. Finally, TOPSIS uses these insights to quantitatively rank strategic alternatives. This integrated approach overcomes the limitations of using each method in isolation, providing a more robust and nuanced analysis. In addition, all computational steps are presented in this section.

Step 1. Building the SWOT matrix: A robust strategic approach requires a comprehensive analysis. Therefore, the first step is to build a solid SWOT matrix. Thus, appropriate subfactors are identified through literature data and expert judgment. The matrix is then completed by identifying alternative strategies. In particular, when alternative strategies are to be developed as a result of SWOT analysis, the TOWS matrix appears as a useful tool. The TOWS matrix

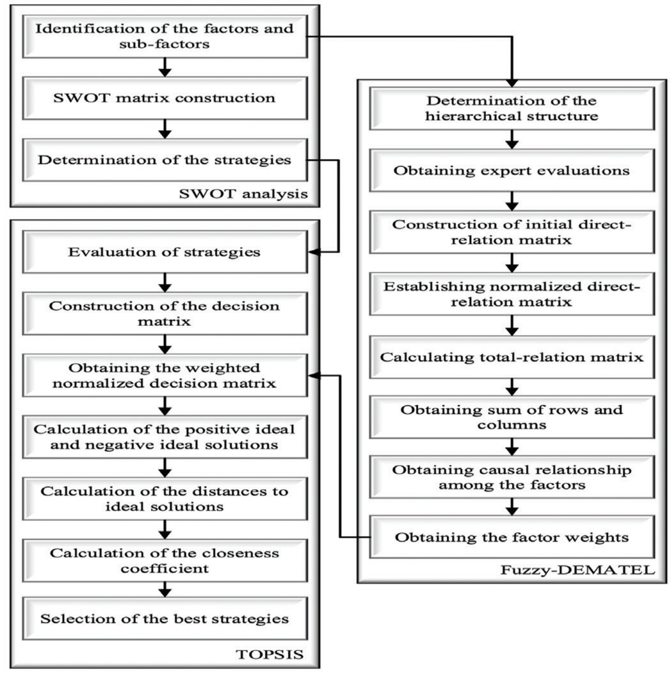

Figure 1. *Framework of the integrated methodology*

proposed by Ghazinoory et al. [45] is shown in Table 1.

This framework allows effective strategies to be developed by evaluating all factors that emerge from an SWOT analysis. SO strategies use strengths to leverage opportunities. WO strategies focus on eliminating weaknesses by taking advantage of opportunities. ST strategies use strengths to avoid exposure to threats. Finally, WT strategies can be used to develop defensive measures to avoid weaknesses and threats.

Step 2. Determination of the hierarchical structure: In this step, the hierarchical structure between the goal, factors, and sub-factors is established.

Step 3. Obtaining expert evaluations: The pairwise comparison matrices constructed for the identified SWOT factors and subfactors were evaluated by the experts. For this purpose, a DM group of experts with relevant knowledge and experience is selected. DMs defined their judgments using the linguistic scale presented in Table 2.

Step 4. Construction of initial direct-relation matrix: Once the DM assessments are obtained, the linguistic expressions are quizzified and aggregated to establish a direct-relation matrix (A). $A = [a_{ij}]$ is a ($n \times n$) non-negative matrix, where a_{ij} is the direct impact of factor i on factor j. The diagonal elements of matrix A (where $i = j$) are equal to zero.

Step 5. Establish a normalized direct-relation matrix: In this step, the normalized direct-relation fuzzy matrix (D) is established. Where, $D = [d_{ij}]$, all diagonal elements are equal to zero, and all elements are complying with $d_{ij} \in [0,1]$. D can be obtained using Equation 1.

***Table 2.** Linguistic scale for expert judgments*

Linguistic scale	Definition	Triangular fuzzy numbers
No	No influence	(0, 0, 0.25)
VL	Very low influence	(0, 0.25, 0.50)
L	Low influence	(0.25, 0.50, 0.75)
H	High influence	(0.50, 0.75, 1)
VH	Very high influence	(0.75, 1, 1)

$$D = \frac{1}{\max\limits_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}} \quad (1)$$

Step 6. Calculating the total-relation matrix: After normalizing the initial direct-relation matrix, the next step is to calculate the total-relation matrix. The total-relation matrix, T, is calculated using Equation 2.

$$T = D(I - D)^{-1} \quad (2)$$

where, D is the normalized direct-relation fuzzy matrix, and I stands for a $n \times n$ identity matrix.

Step 7. Obtaining r_i and c_j values: In this step, the values of r_i and c_j are calculated using Equations 3 and 4.

$$r_i = \sum_{1 \le j \le n} t_{ij} \quad (3)$$

$$c_j = \sum_{1 \le i \le n} t_{ij} \quad (4)$$

where, r_i denotes all influence given by criterion i to all other factors, c_j indicates the degree of influence. Then the r_i and c_j values defuzzified using the Center of Area technique shown in Equation 5.

$$A = \int a \frac{\mu_x(a)da}{\int \mu_x da} \quad (5)$$

Step 8. Obtaining the causal relationship: Once the r_i and c_j values are obtained, $(r_i + c_j)$ and $(r_i - c_j)$ values are calculated to obtain the causal relationship among the factors. $(r_i + c_j)$ denotes the mutual influence of criterion i and other system factors, $(r_i - c_j)$ represents the net influence of criterion i on the system. If $r_i - c_j > 0$, the factor i is in the cause group, while if $r_i - c_j < 0$, the factor i is in the effect group. Then, a causal diagram is constructed based on these values to simply visualize the complex interrelationships between the factors.

Step 9. Calculating weights: In this step, the weights of the factors and sub-factors are calculated using Equations 6 and 7 [49].

$$\omega_i = \sqrt{(r_i + c_j)^2 + (r_i - c_j)^2} \quad (6)$$

$$\widetilde{\omega}_i = \frac{\omega_i}{\sum_{i=1}^{n} \omega_i} \quad (7)$$

where, ω_i denotes importance of any factor, $\widetilde{\omega}_i$ stands for the final local weights of the factors and subfactors obtained from the normalization of ω_i values. Finally, the local weights of the subfactors are multiplied by the local weights of the relevant factors to obtain the global weights (W_i) of each subfactor.

Step 10. Evaluation of strategies: In this step, DMs evaluate the relevance of the strategies identified in the first step to SWOT factors using the linguistic scale presented in Table 3.

Step 11. Construction of the decision matrix: Once the DM evaluations are obtained from each expert, the decision matrix, $X = [x_{ij}]$, is derived by quizzifying the linguistic values.

Step 12. Obtaining the weighted normalized decision matrix: The normalized decision matrix, $\tilde{X} = [\tilde{x}_{ij}]$, is calculated by using Equation 8.

$$\tilde{x}_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \quad (8)$$

Then, the factor weights obtained in step 7, $\widetilde{\omega}_i$, are multiplied with the $\tilde{x}_{ij}$ values to calculate the weighted normalized decision matrix, $\tilde{\tilde{X}} = [\tilde{\tilde{x}}_{ij}]$.

$$\tilde{\tilde{x}}_{ij} = \tilde{x}_{ij} \otimes \widetilde{\omega}_i \quad (9)$$

Step 13. Calculation of the positive and negative ideal solutions: In this step, the positive and negative ideal solutions, A^+ and A^-, calculated by using Equations 10 and 11.

$$A^+ = (\tilde{\tilde{x}}_1^+, \tilde{\tilde{x}}_2^+, \cdots, \tilde{\tilde{x}}_n^+) = \{max(\tilde{\tilde{x}}_{ij})\} \quad (10)$$

$$A^- = (\tilde{\tilde{x}}_1^-, \tilde{\tilde{x}}_2^-, \cdots, \tilde{\tilde{x}}_n^-) = \{min(\tilde{\tilde{x}}_{ij})\} \quad (11)$$

Step 14. Calculation of the distances to ideal solutions: The distances of each alternative to the ideal solutions, D_i^+ and D_i^-, are obtained using Equations 12 and 13.

$$D_i^+ = \sqrt{\sum_{j=1}^{n} (\tilde{\tilde{x}}_{ij} - \tilde{\tilde{x}}_j^{+})^2} \quad (12)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} (\tilde{\tilde{x}}_{ij} - \tilde{\tilde{x}}_j^{-})^2} \quad (13)$$

***Table 3.** Linguistic scale for TOPSIS*

Scale	Linguistic variables
1	Very low
2	Low
3	Moderate
4	High
5	Very high

TOPSIS: Order of Preference by Similarity to Ideal Solution where D_i^+ is the distance from A^+, and D_i^- is the distance from A^-.

Step 15. Calculation of the closeness coefficient: Then, the relative closeness to the ideal solution, $\mathscr{C}_i^*$, is calculated using Equation 14.

$$\mathcal{C}_i^* = \frac{D_i^+}{D_i^+ - D_i^-} \quad (14)$$

Step 16. Selection of the best strategies: Finally, the strategies are ranked in descending order according to their $\mathscr{C}_i^*$values. The strategies with the highest $\mathscr{C}_i^*$values are the closest to the ideal solution, i.e., they were considered the best strategies.

4. Practical Implementation of the Methodology

4.1. Numerical Analysis

This section describes the application of the integrated methodology for the strategic management of offshore tugboat and support vessel operations. Initially, a group of 5 experts with in-depth knowledge and experience on the subject was formed to contribute to the DM process. The detailed DM profiles are presented in Table 4.

Then, the computational steps of the integrated methodology presented in section 3.4 are applied.

A comprehensive literature review formed the initial framework for identifying key SWOT factors by drawing on relevant studies on maritime operations, strategic management, and offshore vessel operations. In this study, the selection of experts was crucial to ensure the validity and reliability of the SWOT-TOWS and DEMATEL analyses. Twelve experts were chosen from various maritime industry segments to create the SWOT matrix, including senior managers from companies like ALP Maritime, Boskalis, Spanopoulos, Iskolden, Tüpraş, Uzmar, and Ata Offshore, as well as academic researchers, technical experts, and industry consultants. These experts were selected based on their extensive knowledge, experience, and active involvement in the maritime sector. A comprehensive questionnaire was designed to identify and evaluate relevant SWOT factors for offshore tugboat and support vessel operations. The questionnaire was distributed electronically to the selected experts. As an initial analysis step, a third-party analysis helped compile a SWOT list highlighting the most significant strengths, weaknesses, opportunities, and threats relevant to offshore operations. A total of 20 factors were identified and are presented in Table 5.

Step 1. Building the SWOT matrix: Based on the literature data and expert consultations, internal (strengths and weaknesses) and external (opportunities and threats) factors related to offshore tugboat and support vessel operations were identified. Thus, a SWOT matrix was created by identifying five subfactors for each factor. Finally, the SWOT matrix was constructed by identifying eight alternative strategies within the framework of the TOWS matrix presented in Table 1. The final TOWS matrix is presented in Table 5.

Step 2. Determination of the hierarchical structure: The hierarchical structure based on SWOT factors and sub-factors is presented in Figure 2.

Step 3. Obtaining expert evaluations: To determine the hierarchy between SWOT factors and subfactors, DMs performed pairwise comparisons using the linguistic scale presented in Table 2. The data of the "Strengths" factor obtained from five DMs is shared as an example in Table 6. Pairwise comparisons were also performed for the main factors, weaknesses, threats, and opportunities identified by all DMs.

Step 4. Construction of initial direct-relation matrix: After obtaining the evaluations from all five DMs, the linguistic values were aggregated by converting them into triangular fuzzy numbers according to the scale in Table 2. Thus, five separate initial direct-relation fuzzy matrices were constructed for the goal and each factor. As an example, the fuzzification of the linguistic assessment from DM1 is presented in Table 6. After the evaluations of the other four DMs are quizzified in the same manner, the aggregated expert evaluation matrix (i.e., the initial direct-relation matrix) is obtained by averaging all evaluations. The initial direct-relation matrix of the strengths is shown in Table 6 as an example.

Table 4. *Profile of the DMs*

DM	Professional rank	Sea experience	Current profession	Educational level
1	Master	10	Operation Manager	BSc
2	Chief Officer	7	Academician	PhD
3	Master	12	Fleet Manager	MSc
4	Master	21	Chartering Manager	BSc
5	Master	15	Fleet Manager	MSc

DMs: Decision-makings

Table 5. *SWOT matrix*

	Strengths			Weaknesses	
SWOT	S_1		**Experienced Crew:** Skilled personnel with expertise in handling complex offshore operations [50].	W_1	**High Operational Costs:** Significant expenses related to fuel, maintenance, and crew wages reduce overall profitability [51].
	S_2		**Advanced technology:** Modern tugboats equipped with state-of-the-art technology, enhancing safety and efficiency [6].	W_2	**Dependency on a Single Market:** Heavy reliance on the oil and gas sector makes businesses in this industry vulnerable to market fluctuations in this industry [52].
	S_3		**Strong Client Relationships:** Established long-term contracts and trusted partnerships with leading oil and gas companies [53].	W_3	**Vulnerability to Weather Conditions:** Operations are highly susceptible to disruptions caused by adverse weather conditions, which affect service delivery [3].
	S_4		**Diversified Service Offerings:** Provide a wide range of services, including towing, escorting, and offshore support, to enhance market adaptability [54].	W_4	**High-capital investment:** Significant capital investment required for fleet maintenance, upgrades, and expansion, which may strain financial resources [55,56].
	S_5		**Innovation in Vessel Design and Efficient Resource Management:** Continuous improvement and modernization of vessel designs, coupled with optimized use of fuel, spare parts and other resources, enhance operational efficiency and reduce costs while meeting evolving industry standards and client needs [57].	W_5	**Limited Innovation Culture and Research Gaps:** A lack of a proactive approach toward innovation and insufficient research in the literature related to offshore tugboat and support vessel operations may hinder the adoption of new technologies and best practices, impacting the company's ability to remain competitive and efficient [58].
Opportunities	**SO_1**		Leverage strong client relationships and diversified service offerings to expand into emerging markets and meet increasing demand for offshore services. By capitalizing on existing relationships and diverse capabilities, the company can broaden its market presence and secure more stable revenue streams.	WO_1	Address high operational costs and dependency on a single market by adopting technological advancements that improve fuel efficiency, reduce maintenance expenses, and support diversification into renewable energy projects and emerging markets. Additionally, they should enhance crew retention programs and adopt new training methods that utilize government incentives aimed at workforce development.
O_1	**Expanding renewable energy sources:** The growing demand for offshore windfarms and other renewable energy projects offers new avenues for diversification and growth [59].				
O_2	**Technological Advancements & Fleet Modernization:** Opportunities to adopt cutting-edge technologies, such as autonomous vessels and advanced navigation systems, to enhance operational efficiency. In addition, there are opportunities to invest in new, energy-efficient vessels that reduce operating costs and improve competitiveness [60].				

Table 5. *Continued*

	Strengths			Weaknesses	
O_3	**Emerging Markets**: Expansion into developing regions with increasing offshore exploration and production activities, providing access to new markets [61].	**SO_2**	Enhance operational efficiency and vessel design innovation while implementing eco-friendly operations to capitalize on technological advancements and fleet modernization. This strategy also involves aligning with government incentives to further the use of alternative energy sources and reduce environmental impact, thus ensuring a competitive edge.	**WO_2**	Improve marketing strategies and strengthen vulnerability to weather conditions by investing in fleet modernization and adopting advanced navigation systems and weather forecasting technologies, thereby ensuring better operational resilience and market adaptability.
O_4	**Increased demand for offshore services:** The growing global energy demand, particularly in offshore oil and gas, could lead to an increased need for support vessels [62].				
O_5	**Rising Importance of Maritime Safety:** An increasing focus on maritime safety and risk management could create a demand for specialized services, such as emergency response and safety training [63].				
Threats	ST_1		Using experienced crew members, advanced technology, and innovation in vessel design and resource management to maintain operational efficiency, mitigate the impacts of market volatility, and stay ahead of technological disruptions, ensuring long-term competitiveness.	**WT_1**	Reduce high operational costs and streamline logistics by implementing cost-saving technologies and automated systems, addressing the threats of intense competition and environmental risks. This involves developing contingency plans for weather-related disruptions.
T_1	**Market Volatility:** Fluctuations in global oil prices could reduce demand for offshore support services, affecting revenue stability [64].				
T_2	**Environmental Regulations:** Increasingly stringent environmental regulations may increase operational costs and challenges [65].				
T_3	Geopolitical Risks: Political instability in key operational regions can disrupt activities and affect the stability of contracts [66].	**ST_2**	Strengthen strong client relationships and resilient fleet to secure contracts in politically stable regions while minimizing the risks associated with geopolitical instability while optimizing operational costs to reduce the financial impact of economic downturns.	**WT_2**	Mitigate the risks associated with high capital investments and address the research gaps by securing long-term financing options and exploring strategic alliances, while improving marketing strategies to enhance brand visibility and counter market volatility.
T_4	Environmental Risks: The potential for environmental incidents, such as oil spills, poses a risk to reputation and financial stability [67].				
T_5	Economic Downturns: Global economic downturns could reduce investment in offshore projects, impacting demand for services [68].				

SWOT: Strengths, Weaknesses, Opportunities, and Threats

Step 5. Establish a normalized direct-relation matrix: The initial direct-relation matrices were normalized by applying Equation 1. The normalized direct-relation matrix calculated for the strengths is shown in Table 6 as an example.

Step 6. Calculating the total-relation matrix: After obtaining the normalized direct-relation matrix, the total-relation matrix was calculated using Equation 2. The total relation matrix calculated for strengths is presented as an example in Table 6.

Step 7. Obtaining r_i and c_j values: In this step, r_i and c_j values were obtained and defuzed by using Equations 3-5. The calculated strength values are shown in Table 6 as an example.

Step 8. Obtaining the causal relationship: Once the r_i and c_j values are obtained, $(r_i + c_j)$ and $(r_i - c_j)$ values are calculated to obtain the causal relationship among the factors. The causal relationship among strength subfactors is presented in Table 6 as an example.

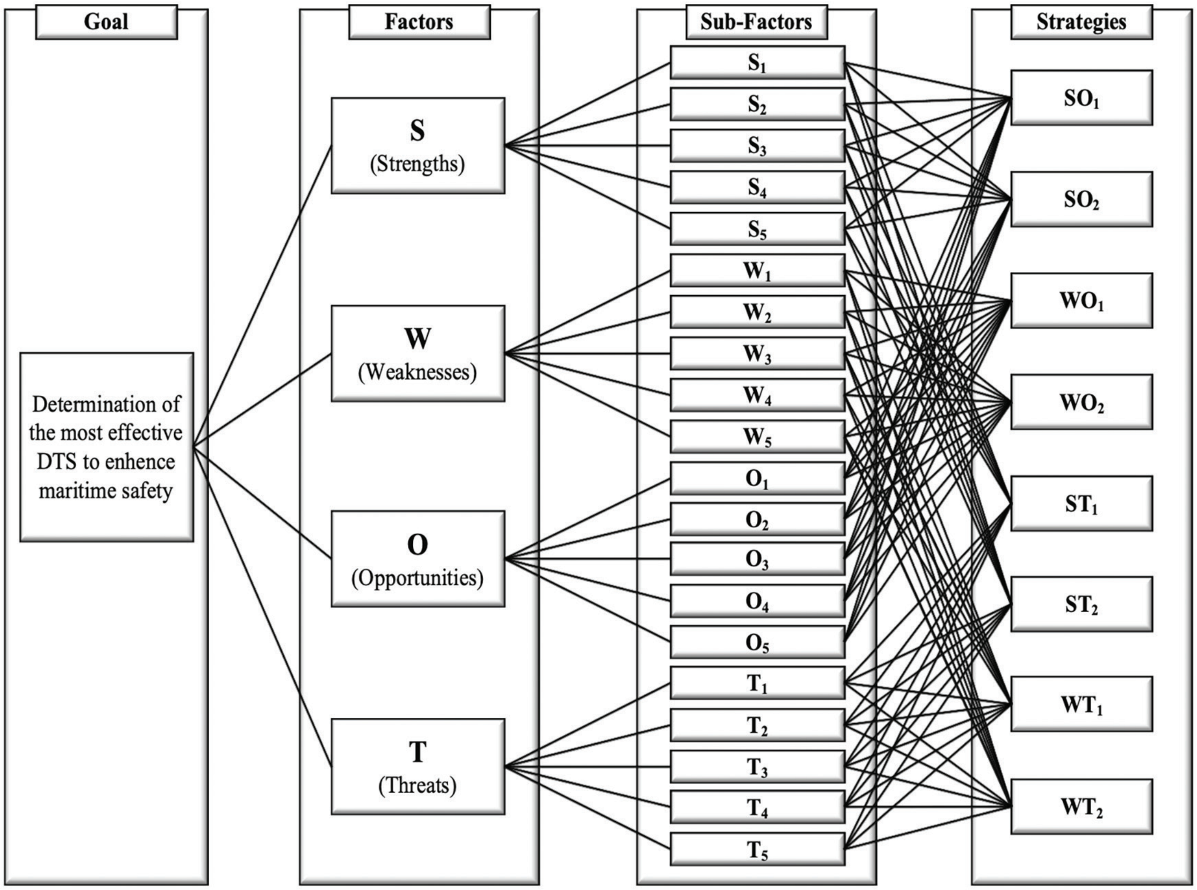

Figure 2. *Hierarchical structure*

Step 9. Calculate the weights: After r_i and c_j values, the weights of the goal and each factor were calculated using Equations 6 and 7. The calculated local and global weights (W_i) are shown in Table 7 and also illustrated in Figures 3 and 4.

Step 10. Evaluation of strategies: The DMs were asked to assess the relevance of the identified strategies to SWOT factors using the linguistic scale presented in Table 3.

Step 11. Construction of the decision matrix: After obtaining the DM evaluations, the linguistic expressions were quantified according to the scale presented in Table 3. Then, all matrices were aggregated, and the decision matrix presented in Table 8 was constructed.

Step 12. Obtaining the weighted normalized decision matrix: The decision matrix was normalized using Equations 8 and 9. Then, the normalized decision matrix is weighted with the global weight values (W_i) obtained in Step 9. Thus, the weighted-normalized decision matrix presented in Table 9 was constructed.

Step 13. Calculation of the positive and negative ideal solutions: The positive (A^+) and the negative (A^-) ideal solutions were calculated using Equations 10-11. $A^+$and A^- values are presented in Table 9.

Step 14. Calculation of distance to ideal solutions: The distances $D_i^+$and D_i^-, of each alternative to the ideal solutions were calculated using Equations 12 and 13. The results are presented in Table 10.

Step 15. Calculation of the closeness coefficient: Then, the relative closeness to the ideal solution, C_i^*, is calculated using Equation 14. C_i^* values of each strategy are also shown in Table 10.

Step 16. Selection of the best strategies: Finally, all alternative strategies were ranked in descending order according to their C_i^* values. The prioritized order of the strategies is obtained as $WO_1 > SO_2 > ST_1 > WT_2 > ST_2 > SO_1 > WT_1 > WO_2$. Results and the prioritized order of the strategies are also illustrated in Figure 5.

These values, derived from the TOPSIS analysis, provide a quantitative measure of each strategy's effectiveness in addressing the complex challenges identified through the SWOT-TOWS and Fuzzy DEMATEL analyses. This prioritization serves as a valuable guideline for decision-

Table 6. DEMATEL application steps for the strengths

DMs' pairwise comparison matrices of DMs for strengths

	DM$_1$					DM$_2$					DM$_3$					DM$_4$					DM$_5$				
	S$_1$	S$_2$	S$_3$	S$_4$	S$_5$	S$_1$	S$_2$	S$_3$	S$_4$	S$_5$	S$_1$	S$_2$	S$_3$	S$_4$	S$_5$	S$_1$	S$_2$	S$_3$	S$_4$	S$_5$	S$_1$	S$_2$	S$_3$	S$_4$	S$_5$
S$_1$	NO	L	VH	H	H	NO	VL	VH	VH	VH	NO	L	H	H	H	NO	H	VH	L	H	NO	L	VH	H	L
S$_2$	VH	NO	VH	H	VH	H	NO	H	H	H	VH	NO	VH	VH	VH	VH	NO	VH	H	VH	VH	NO	VH	L	VH
S$_3$	NO	H	NO	NO	VL	NO	H	NO	VL	NO	VL	VH	NO	NO	VL	NO	H	NO	VL	NO	L	L	NO	NO	VL
S$_4$	H	NO	L	NO	L	VH	VL	VL	NO	L	H	NO	H	NO	VL	L	NO	L	NO	L	H	VL	L	NO	H
S$_5$	NO	VH	VL	H	NO	VL	H	VL	VH	NO	NO	VH	L	H	NO	VL	VH	VL	L	NO	NO	VH	NO	H	NO

Fuzzified pairwise comparison matrix of *DM$_1$* for strengths

	S$_1$	S$_2$	S$_3$	S$_4$	S$_5$
S$_1$	(0, 0, 0.25)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.5, 0.75, 1)	(0.5, 0.75, 1)
S$_2$	(0.75, 1, 1)	(0, 0, 0.25)	(0.75, 1, 1)	(0.5, 0.75, 1)	(0.75, 1, 1)
S$_3$	(0, 0, 0.25)	(0.5, 0.75, 1)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0.25, 0.5)
S$_4$	(0.5, 0.75, 1)	(0, 0, 0.25)	(0.25, 0.5, 0.75)	(0, 0, 0.25)	(0.25, 0.5, 0.75)
S$_5$	(0, 0, 0.25)	(0.75, 1, 1)	(0, 0.25, 0.5)	(0.5, 0.75, 1)	(0, 0, 0.25)

Initial direct-relation matrix of the strengths

	S$_1$	S$_2$	S$_3$	S$_4$	S$_5$
S$_1$	(0, 0, 0.25)	(0.25, 0.5, 0.75)	(0.7, 0.95, 1)	(0.5, 0.75, 0.95)	(0.5, 0.75, 0.95)
S$_2$	(0.7, 0.95, 1)	(0, 0, 0.25)	(0.7, 0.95, 1)	(0.5, 0.75, 0.95)	(0.7, 0.95, 1)
S$_3$	(0.05, 0.15, 0.4)	(0.5, 0.75, 0.95)	(0, 0, 0.25)	(0, 0.1, 0.35)	(0, 0.15, 0.4)
S$_4$	(0.5, 0.75, 0.95)	(0, 0.1, 0.35)	(0.25, 0.5, 0.75)	(0, 0, 0.25)	(0.25, 0.5, 0.75)
S$_5$	(0, 0.1, 0.35)	(0.7, 0.95, 1)	(0.05, 0.25, 0.5)	(0.5, 0.75, 0.95)	(0, 0, 0.25)

Normalized direct-relation matrix for strength

	S$_1$	S$_2$	S$_3$	S$_4$	S$_5$
S$_1$	(0, 0, 0.06)	(0.1, 0.14, 0.18)	(0.27, 0.26, 0.24)	(0.19, 0.21, 0.23)	(0.19, 0.21, 0.23)
S$_2$	(0.27, 0.26, 0.24)	(0, 0, 0.06)	(0.27, 0.26, 0.24)	(0.19, 0.21, 0.23)	(0.27, 0.26, 0.24)
S$_3$	(0.02, 0.04, 0.1)	(0.19, 0.21, 0.23)	(0, 0, 0.06)	(0, 0.03, 0.08)	(0, 0.04, 0.1)
S$_4$	(0.19, 0.21, 0.23)	(0, 0.03, 0.08)	(0.1, 0.14, 0.18)	(0, 0, 0.06)	(0.1, 0.14, 0.18)
S$_5$	(0, 0.03, 0.08)	(0.27, 0.26, 0.24)	(0.02, 0.07, 0.12)	(0.19, 0.21, 0.23)	(0, 0, 0.06)

Total-relation matrix of strengths

	S$_1$	S$_2$	S$_3$	S$_4$	S$_5$
S$_1$	(0.15, 0.24, 0.66)	(0.28, 0.41, 0.83)	(0.42, 0.53, 0.91)	(0.34, 0.45, 0.89)	(0.33, 0.45, 0.87)
S$_2$	(0.43, 0.51, 0.86)	(0.26, 0.36, 0.78)	(0.5, 0.6, 0.96)	(0.41, 0.52, 0.94)	(0.46, 0.56, 0.93)
S$_3$	(0.1, 0.18, 0.49)	(0.25, 0.33, 0.64)	(0.11, 0.17, 0.52)	(0.09, 0.18, 0.54)	(0.1, 0.2, 0.54)
S$_4$	(0.25, 0.33, 0.68)	(0.11, 0.23, 0.62)	(0.21, 0.34, 0.72)	(0.1, 0.19, 0.61)	(0.18, 0.31, 0.7)
S$_5$	(0.17, 0.25, 0.59)	(0.37, 0.44, 0.76)	(0.2, 0.33, 0.69)	(0.33, 0.41, 0.77)	(0.16, 0.24, 0.61)

Results of applying DEMATEL to the strengths

	r_i	c_j	$(r_i + c_j)$	$(r_i - c_j)$
S$_1$	2.588	1.960	4.548	0.629
S$_2$	3.036	2.225	5.261	0.812
S$_3$	1.474	2.405	3.879	-0.931
S$_4$	1.863	2.259	4.122	-0.396
S$_5$	2.102	2.215	4.317	-0.114

DEMATEL: Fuzzy Decision Making Trial and Evaluation Laboratory, DMs: Decision-makings

Table 7. *Local and global weights*

Factors	Local Weights $(\tilde{\omega}_i)$	Sub-Factors	Local Weights $(\tilde{\omega}_i)$	Global Weights (W_i)
S	0.2514	S_1	0.2053	0.052
		S_2	0.2380	0.060
		S_3	0.1784	0.045
		S_4	0.1852	0.047
		S_5	0.1931	0.049
W	0.2532	W_1	0.2247	0.057
		W_2	0.2306	0.058
		W_3	0.1285	0.033
		W_4	0.2285	0.058
		W_5	0.1877	0.048
O	0.2468	O_1	0.1795	0.044
		O_2	0.2100	0.052
		O_3	0.2222	0.055
		O_4	0.1931	0.048
		O_5	0.1951	0.048
T	0.2486	T_1	0.2253	0.056
		T_2	0.1748	0.043
		T_3	0.1844	0.046
		T_4	0.1977	0.049
		T_5	0.2178	0.054

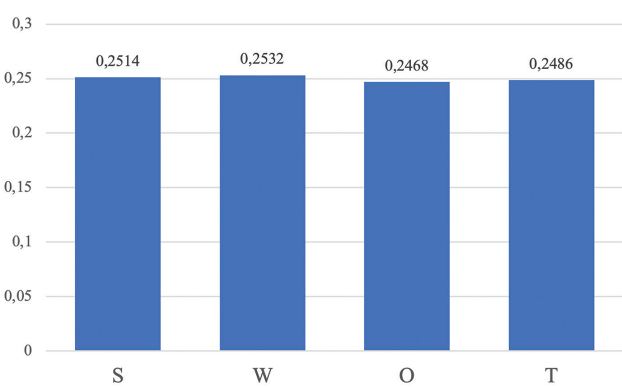

Figure 3. *Weighting of the SWOT factors*

makers in the offshore tugboat and support vessel industries, providing a rational, data-driven foundation for strategic planning and resource allocation. However, it is important to consider that although this ranking presents a clear priority order, the implementation of these strategies should be tailored to the specific context of each organization. In addition, the industry environment may change rapidly, necessitating continuous evaluation and adaptation of strategic plans.

4.2. Sensitivity Analysis

This section presents a sensitivity analysis that explores the effects of the weights obtained using the SWOT-TOWS-DEMATEL method on the prioritization of strategies. In addition to the results of the numerical analysis (i.e., the base case, eleven more different cases with alternative local weights $(\tilde{\omega}_i)$ of the SWOT factors were created (Büyüközkan et al., 2021). The alternative cases are listed in Table 11.

Then, subfactor global weights (W_i) are calculated with reference to the factor weights determined for each alternative case (Table 12).

The TOPSIS method is then reapplied by revising the global weights to obtain strategy prioritizations for each case.

The C_i^* values of the strategies for all the different cases are presented in Table 13, and the final prioritization of the strategies for all the different cases is presented in Table 14.

The prioritization of strategies for each case is illustrated in Figure 6. It can be seen that there are small differences in the ranking of the strategies. These small changes do not affect validity. For example, the WO1 strategy was calculated as the most prioritized strategy in 10 out of 11 alternative cases. Thus, the results of the base case study can be validated. Furthermore, WO1 emerged as the best strategy in 11 cases, followed by SO2 and ST1 as the other suitable strategies.

5. Findings and Discussion

Adopting advanced technologies to improve fuel efficiency and reduce maintenance costs is a key strategy that should help to overcome the significant challenges brought by high operational expenses and market dependencies [69,70]. This issue is central to achieving sustainable growth in the industry, and the WO1 strategy aims at innovative, particularly ecological, solutions to alleviate these cost-related challenges. By focusing on reducing expenses related to fuel, maintenance, and crew wages, this approach not only promises substantial cost savings but also aligns companies with global sustainability goals. This emphasis on cost-effectiveness and sustainability enhances competitive advantage in a market that is increasingly shaped by these factors. The SO2 strategy focuses on improving operational efficiency through innovative vessel designs, including eco-friendly practices, and modernizing the fleet with advanced technologies. This is in conjunction with government incentives for autonomous vessels and advanced navigation systems, which positions the company to further lead efforts toward sustainable fleet

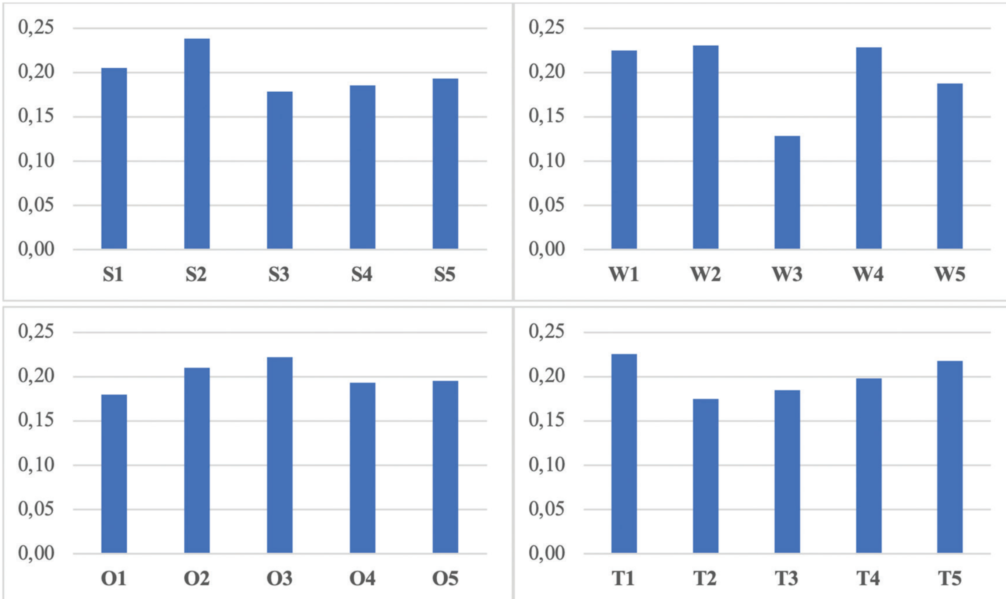

Figure 4. *Weights of the SWOT subfactors*

Table 8. *Initial decision matrix*

	SO_1	SO_2	WO_1	WO_2	ST_1	ST_2	WT_1	WT_2
S_1	4.40	4.60	4.40	1.20	4.20	4.80	4.60	3.20
S_2	4.20	4.60	4.60	4.20	4.80	4.60	4.60	4.60
S_3	4.60	4.80	4.40	1.80	4.80	4.80	3.80	4.20
S_4	4.80	2.80	4.60	3.40	4.80	4.80	3.80	4.80
S_5	4.60	4.60	4.60	4.80	4.60	4.80	4.80	4.60
W_1	3.40	4.80	4.60	3.80	2.80	3.20	4.80	3.60
W_2	4.80	2.80	5.00	4.60	4.20	4.60	4.20	4.20
W_3	1.20	4.20	4.20	1.20	4.40	2.20	1.40	3.80
W_4	2.80	3.80	4.60	2.80	2.80	3.60	3.80	4.80
W_5	4.80	4.80	4.60	4.60	4.80	4.20	4.80	4.20
O_1	4.80	4.60	4.80	4.80	4.20	4.80	4.80	4.80
O_2	4.80	4.80	4.60	4.80	4.80	4.60	4.80	4.60
O_3	2.20	3.80	3.80	2.20	2.40	2.20	1.80	2.40
O_4	2.80	3.20	4.20	2.80	2.20	3.40	1.80	2.20
O_5	4.80	4.80	4.80	4.80	4.80	2.80	2.80	3.20
T_1	3.80	4.20	4.80	2.80	4.60	2.80	3.20	4.80
T_2	4.80	4.60	4.80	4.80	4.80	4.80	4.80	4.80
T_3	3.80	2.80	2.80	2.80	3.80	4.60	2.80	2.80
T_4	3.20	4.80	4.60	4.80	4.60	3.80	4.80	4.80
T_5	4.80	4.20	4.80	4.20	3.80	3.80	4.20	4.80

modernization [71]. Continuous innovation empowers the industry to meet increasing market and regulatory demands, reduce environmental impact, and maintain leadership by attracting new and existing clients.

The competitive advantage can be fueled not only by enabling a skilled crew but also by using advanced technology and practicing resource management innovation in the continuously volatile market with fast changes in technologies to ensure long-term success [72,73]. Such a strategy positions the industry not only to respond to but also to predict changes in the market and technology. Such strategic direction enables companies to surmount challenges and maintain leadership in a dynamic environment.

Companies can mitigate risks associated with high capital investments and research gaps and enhance brand visibility by securing long-term financing options and forming strategic alliances [74]. A strong financial foundation strengthens a company's position against market volatility and builds resilience to sustain growth. According to Pringpong et al. [75], the risks associated with geopolitical instability and financial stressors due to economic decline can be mitigated by strengthening client relationships and optimizing operational costs. This ensures that firms remain resilient even when such unexpected external shocks occur because their revenue streams are stable and efficient. Those firms that focus on retaining clients and optimizing costs can better navigate economically ambiguous climates to sustain their competitive advantage.

It would ensure a stable revenue stream by leveraging strong client relationships and diversified service offerings and expanding into growth markets with increasing demand for offshore services [76]. This strategy capitalizes on growth opportunities in emerging markets and establishes a robust global presence. Diversifying business services and building deep customer relationships enhance the ability to

Table 9. *The weighted-normalized decision matrix*

	W_i	SO_1	SO_2	WO_1	WO_2	ST_1	ST_2	WT_1	WT_2	A^+	A^-
S_1	0.052	0.020	0.021	0.020	0.005	0.019	0.021	0.021	0.014	0.021	0.005
S_2	0.060	0.020	0.021	0.021	0.020	0.022	0.021	0.021	0.021	0.022	0.020
S_3	0.045	0.017	0.018	0.016	0.007	0.018	0.018	0.014	0.016	0.018	0.007
S_4	0.047	0.018	0.011	0.018	0.013	0.018	0.018	0.015	0.018	0.018	0.011
S_5	0.049	0.017	0.017	0.017	0.018	0.017	0.018	0.018	0.017	0.018	0.017
W_1	0.057	0.017	0.024	0.023	0.019	0.014	0.016	0.024	0.018	0.024	0.014
W_2	0.058	0.023	0.013	0.024	0.022	0.020	0.022	0.020	0.020	0.024	0.013
W_3	0.033	0.004	0.015	0.015	0.004	0.016	0.008	0.005	0.014	0.016	0.004
W_4	0.058	0.015	0.021	0.025	0.015	0.015	0.020	0.021	0.027	0.027	0.015
W_5	0.048	0.018	0.018	0.017	0.017	0.018	0.015	0.018	0.015	0.018	0.015
O_1	0.044	0.016	0.015	0.016	0.016	0.014	0.016	0.016	0.016	0.016	0.014
O_2	0.052	0.019	0.019	0.018	0.019	0.019	0.018	0.019	0.018	0.019	0.018
O_3	0.055	0.016	0.027	0.027	0.016	0.017	0.016	0.013	0.017	0.027	0.013
O_4	0.048	0.016	0.018	0.024	0.016	0.013	0.020	0.010	0.013	0.024	0.010
O_5	0.048	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.013	0.019	0.011
T_1	0.056	0.019	0.021	0.024	0.014	0.023	0.014	0.016	0.024	0.024	0.014
T_2	0.043	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
T_3	0.046	0.018	0.014	0.014	0.014	0.018	0.022	0.014	0.014	0.022	0.014
T_4	0.049	0.012	0.019	0.018	0.019	0.018	0.015	0.019	0.019	0.019	0.012
T_5	0.054	0.021	0.019	0.021	0.019	0.017	0.017	0.019	0.021	0.021	0.017

Table 10. *Ranking strategies*

Strategies	D_i^+	D_i^-	C_i^*	Prioritization
SO_1	0.025	0.026	0.511	6
SO_2	0.018	0.032	0.642	2
WO_1	0.009	0.037	0.798	1
WO_2	0.033	0.016	0.329	8
ST_1	0.023	0.028	0.550	3
ST_2	0.023	0.027	0.539	5
WT_1	0.028	0.023	0.450	7
WT_2	0.022	0.026	0.546	4

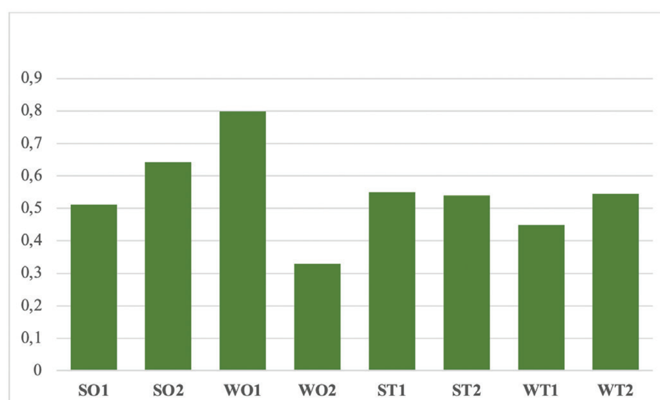

Figure 5. *Results and prioritized order of strategies*

adapt and make future profits. The adoption of cost-saving technologies and automation may facilitate cost operations, augmenting the resistance to competition and environmental variables, and even provide an opportunity for weather disruption [77]. Fleet modernization with good navigation systems will increase operational resilience and market adaptability; for example, a critical factor influencing a company's ability to cope with weather variables [78]. In recent years, when world trade has faced the challenges of climate change and intensifying competition, results have been obtained that emphasize how conservative methods used in current management systems should be used to make operational management systems more environmentally friendly, competitive, and efficient with the development of technology. Based on the results, we can expect that the implementation of environmentally friendly technologies in new offshore vessel construction and design will increase operational efficiency and profitability. Companies that are uncertain about investing in such technological advancements will likely accelerate their orientation toward

***Table 11**. All cases with different SWOT factor weights*

SWOT factor	Base	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11
S	0.251	0.250	0.400	0.200	0.200	0.200	0.400	0.400	0.100	0.400	0.100	0.100
W	0.253	0.250	0.200	0.400	0.200	0.200	0.400	0.100	0.400	0.100	0.400	0.100
O	0.247	0.250	0.200	0.200	0.400	0.200	0.100	0.400	0.100	0.100	0.400	0.400
T	0.249	0.250	0.200	0.200	0.200	0.400	0.100	0.100	0.400	0.400	0.100	0.400

***Table 12**. Sub-factor weights for all cases*

Sub-factor	Base	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11
S_1	0.052	0.051	0.082	0.041	0.041	0.041	0.082	0.082	0.021	0.082	0.021	0.021
S_2	0.060	0.060	0.095	0.048	0.048	0.048	0.095	0.095	0.024	0.095	0.024	0.024
S_3	0.045	0.045	0.071	0.036	0.036	0.036	0.071	0.071	0.018	0.071	0.018	0.018
S_4	0.047	0.046	0.074	0.037	0.037	0.037	0.074	0.074	0.019	0.074	0.019	0.019
S_5	0.049	0.048	0.077	0.039	0.039	0.039	0.077	0.077	0.019	0.077	0.019	0.019
W_1	0.057	0.056	0.045	0.090	0.045	0.045	0.090	0.022	0.090	0.022	0.090	0.022
W_2	0.058	0.058	0.046	0.092	0.046	0.046	0.092	0.023	0.092	0.023	0.092	0.023
W_3	0.033	0.032	0.026	0.051	0.026	0.026	0.051	0.013	0.051	0.013	0.051	0.013
W_4	0.058	0.057	0.046	0.091	0.046	0.046	0.091	0.023	0.091	0.023	0.091	0.023
W_5	0.048	0.047	0.038	0.075	0.038	0.038	0.075	0.019	0.075	0.019	0.075	0.019
O_1	0.044	0.045	0.036	0.036	0.072	0.036	0.018	0.072	0.018	0.018	0.072	0.072
O_2	0.052	0.052	0.042	0.042	0.084	0.042	0.021	0.084	0.021	0.021	0.084	0.084
O_3	0.055	0.056	0.044	0.044	0.089	0.044	0.022	0.089	0.022	0.022	0.089	0.089
O_4	0.048	0.048	0.039	0.039	0.077	0.039	0.019	0.077	0.019	0.019	0.077	0.077
O_5	0.048	0.049	0.039	0.039	0.078	0.039	0.020	0.078	0.020	0.020	0.078	0.078
T_1	0.056	0.056	0.045	0.045	0.045	0.090	0.023	0.023	0.090	0.090	0.023	0.090
T_2	0.043	0.044	0.035	0.035	0.035	0.070	0.017	0.017	0.070	0.070	0.017	0.070
T_3	0.046	0.046	0.037	0.037	0.037	0.074	0.018	0.018	0.074	0.074	0.018	0.074
T_4	0.049	0.049	0.040	0.040	0.040	0.079	0.020	0.020	0.079	0.079	0.020	0.079
T_5	0.054	0.054	0.044	0.044	0.044	0.087	0.022	0.022	0.087	0.087	0.022	0.087

***Table 13**. C_i^* values of the DTSs for all cases*

Sub-factor	Base	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11
SO_1	0.511	0.511	0.625	0.444	0.476	0.503	0.546	0.590	0.416	0.656	0.408	0.457
SO_2	0.642	0.642	0.671	0.611	0.688	0.597	0.638	0.720	0.562	0.632	0.651	0.649
WO_1	0.798	0.798	0.824	0.837	0.848	0.705	0.877	0.891	0.732	0.718	0.909	0.746
WO_2	0.329	0.329	0.257	0.349	0.374	0.328	0.285	0.309	0.352	0.239	0.392	0.381
ST_1	0.550	0.549	0.650	0.509	0.478	0.578	0.595	0.571	0.524	0.726	0.443	0.485
ST_2	0.539	0.537	0.660	0.497	0.479	0.504	0.624	0.600	0.452	0.645	0.433	0.433
WT_1	0.450	0.447	0.557	0.476	0.330	0.422	0.592	0.438	0.459	0.562	0.360	0.264
WT_2	0.546	0.543	0.589	0.600	0.432	0.561	0.654	0.471	0.626	0.616	0.488	0.437

Table 14. *Prioritization of DTSs in all cases*

Sub-factor	Base	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11
SO_1	6	6	5	7	5	6	7	4	7	3	6	4
SO_2	2	2	2	2	2	2	3	2	3	5	2	2
WO_1	1	1	1	1	1	1	1	1	1	2	1	1
WO_2	8	8	8	8	7	8	8	8	8	8	7	7
ST_1	3	3	4	4	4	3	5	5	4	1	4	3
ST_2	5	5	3	5	3	5	4	3	6	4	5	6
WT_1	7	7	7	6	8	7	6	7	5	7	8	8
WT_2	4	4	6	3	6	4	2	6	2	6	3	5

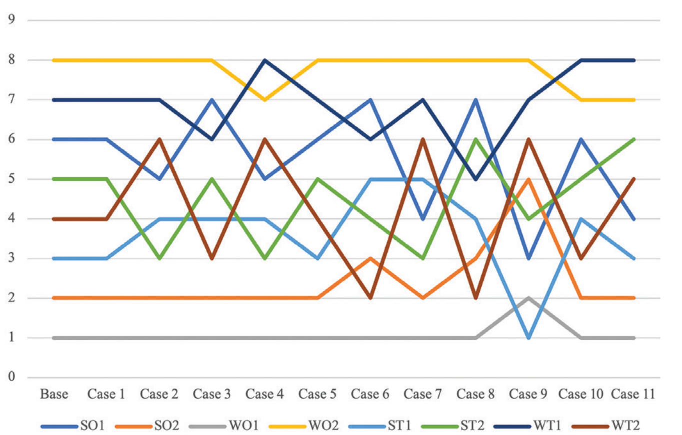

Figure 6. *Changes in the prioritization of the strategies for all cases*

these innovations, based on the evidence presented in this study.

This strategic framework is crucial for decision makers guiding the offshore tugboat and support vessel industries. Companies in this sector can overcome contemporary challenges and seize emerging opportunities by prioritizing technological innovation, operational efficiency, and market diversification. Strategies should be tailored to individual organizations' unique strengths, weaknesses, and market positions.

6. Conclusion

This study investigates critical issues related to strategic maritime management, especially offshore operations. This study highlights the critical role of adopting advanced technologies and innovative strategies to address the challenges faced by the offshore tugboat and support vessel industries. Prioritizing fuel efficiency, maintenance cost reduction, and fleet modernization not only ensures operational sustainability but also aligns with global environmental and market trends. By incorporating SWOT-TOWS analysis into Fuzzy DEMATEL and TOPSIS methods, this study develops an integrated framework that, in detail, represents strategic priorities and their interlinkages of various complexities. While the proposed integrated methodology provides valuable insights, certain limitations should be acknowledged. The DEMATEL method's reliance on subjective expert judgments and the complexity of pairwise comparisons with an increasing number of factors may influence the precision of results, although our sensitivity analysis demonstrates robust outcomes across different scenarios. A state-of-the-art critical literature review and industry experts' insights into the most influential factors shaping the maritime sector are presented in this study. Its core objective is to provide hands-on tools and strategic frameworks for industry leaders to address current challenges and prepare for future opportunities. These advanced DM techniques rank strategic options effectively in this research, emphasizing cost reduction through technology and market diversification. The results of this study confirm that innovation and sustainability are imperative for the maritime sector to maintain competitiveness in an increasingly dynamic global market. This research fills an important gap in the literature on strategic management by providing a customized DM model for maritime operations.

Future studies applying this framework to different maritime scenarios or similar industries are desirable. A long-term study of the effects of some of these emerging technologies, such as AI and automation, on mariners' operations would provide valuable insights. Additionally, further investigation into the role of strategic alliances and client relationship management in mitigating geopolitical and economic uncertainties will provide valuable insights for strengthening the resilience and adaptability of the sector. It would be interesting to conduct longitudinal analyses on how these strategies could contribute to operational efficiency and resilience.

In summary, this research contributes to strategic management in maritime organizations and provides a practical framework for complex DM to navigate the constant changes and challenges of the global marketplace.

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Footnotes

Authorship Contributions

Concept design: A. B. Eke, O. Batmaz, M. F. Gülen, E. Uflaz, and Ö. Arslan, Data Collection or Processing: A. B. Eke, O. Batmaz, M. F. Gülen, and E. Uflaz, Analysis or Interpretation: A. B. Eke, O. Batmaz, M. F. Gülen, E. Uflaz, and Ö. Arslan, Literature Review: A. B. Eke, O. Batmaz, and M. F. Gülen, Writing, Reviewing and Editing: A. B. Eke, O. Batmaz, M. F. Gülen, E. Uflaz, and Ö. Arslan,

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