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Digitalization Strategies at Türkiye's Ro-Ro Ports: A SWOT-FAHP Analysis Approach

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Abstract

Ports aim to restructure terminal operations and address problems to attain better design and efficiency. Recently, digitalization has been the most critical tool for both the management and development of terminal processes. Nonetheless, the feasibility of such a transition is dependent on a clear grasp of the factors influencing digitalization and recognizing their importance. This development also underlines the need for terminal-specific strategies and research. In the study, a research model using SWOT-FAHP was followed and conducted to apply an important scale to 71 SWOT criteria using a survey technique, resulting in a final set of 24 criteria. With expert assessments, a total of 16 strategy themes has been developed for the digitalization strategy matrix of Ro-Ro terminals. In this matrix, four development strategies have been identified: strengths-opportunities (SO) 'adaptation to new technologies internationally' and weaknesses-opportunities (WO) 'employees' adaptation to modern technology'. A total of four development strategies has been identified for strengths-threats (ST), namely 'maintaining operational capabilities against cyber-attacks. In terms of weaknesses and threats (WT), a total of four development strategies has been identified, including 'providing technology training to employees to protect against cyber risks. Addressing digitalization in Ro-Ro terminals through SWOT-FAHP analysis contributes to the literature and assists practitioners in establishing a strategic roadmap.

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JEL Code: L91, Q55, Q56

1. Introduction

The position of maritime transport in global trade and its share in the transport industry has reached approximately 90%, and the importance of maritime transport has become even more pronounced (ICS, 2025; IMO, 2025; Sanchez-Gonzalez et al, 2019; Urban et al., 2024; Zeng et al., 2025). With the increasing volume of global trade, maritime transport has achieved a strategic position thanks to its cost-effectiveness and operational reliability in meeting long-distance and high-tonnage transportation needs (Develi, 2021). However, this situation is open to improvement, and strategies are being developed that increase efficiency, reduce costs in maritime transport, are environmentally friendly, and are compatible with technological changes (Ichimura, et al., 2022; Pavlinović et al., 2023; Zeng et al., 2025). The maritime transport sector might have fallen behind other sectors in adopting digital technologies, but the sector is progressively embracing digital transformation to support environmental sustainability (Sanchez-Gonzalez et al., 2019). For this reason, the impact of digitalization on the maritime industry is being assessed, and it is thought that while the digitalization process may present opportunities for maritime transport, it may also pose threats (İnanlı and Yorulmaz, 2021; Ichimura, et al., 2022; Pavlinović et al., 2023; Raza et al., 2023; Sanchez-Gonzalez et al., 2019; Tijan et al., 2021). Nevertheless, digitalization in maritime transport, which involves many stakeholders, needs to be addressed further (Ichimura, et al., 2022; Song, 2021; Tijan et al., 2021; Patruna and Yorulmaz, 2024; Zeng et al., 2025). Thus, when the research gap is examined in detail rather than from a general perspective (container shipping, ports/terminals, etc.), highly effective digitalization strategies can be developed (Song, 2021; Tijan et al., 2021). In Türkiye and coastal countries, maritime transport, technological applications supporting sustainable development, and digitalization are important areas of development that are gaining momentum. For this reason, identifying specific areas and addressing the factors affecting digitalization, the reflections of the digitalization process and the effects of digitalization will fill the gap in the field, contribute to a strategic roadmap and bring innovation to literature.

As door-to-door transportation becomes more prevalent today using multiple transportation modes in maritime transport, reducing port times and enhancing transport costs are expected, along with increasing transit volumes to achieve the ultimate goal of profitability. In this context, the significance of Ro-Ro transportation, which constitutes a substantial part of the highly competitive maritime transport sector, is rising in Türkiye, as it is globally (Özdemir and Deniz, 2013). Accordingly, this study identifies the factors affecting digitalization processes in Türkiye's Ro-Ro terminals through a literature review and analyses them using SWOT-FAHP methods. In addition, strategies have been developed to leverage the strengths and opportunities of Türkiye's Ro-Ro terminals and mitigate

weaknesses and risks. In this context the questionnaire forms are used to assess the SWOT criteria identified through literature review. To determine strategies, the Fuzzy Analytic Hierarchy Process (FAHP) method is conducted for prioritization.

Although the SWOT-FAHP methodology is usually used in the research, this study distinguishes itself by leveraging this method to analyze the Ro-Ro terminals' digitalization strategy from a different perspective. Thus, this study aims to make a significant contribution to the relevant field, unlike previous research, thanks to the comprehensive analysis of the strategies studied. It examines Ro-Ro terminals and related transportation strategies in the sector based on four different perspectives: strengths and weaknesses, opportunities, and threats. Criteria are prioritized by the FAHP method. Building on these insights, strategies are formulated to enhance and advance future digital transformation initiatives.

Searching for Ro-Ro, SWOT analysis, digitization, and terminal keywords in the Google Scholar database reveals related to studies. Some of these studies comparing Ro-Ro terminals with other types of terminals (Abourraja et al., 2023), analyzing the impact of digital transformation in ports (Heilig et al., 2017), evaluating the role of smart ports and Industry 4.0 (González-Cancelas et al., 2020), the integration of the Internet of Vehicles (IoV) and blockchain as tools to enhance traffic management in Roll-on/Roll-off (Ro-Ro) terminals (Gromule et al., 2023), Aiming to understand the operational requirements for a RORO terminal and the benefits that can be gained from implementing these technologies, alongside the development of artificial intelligence and autonomous vehicle technology (Hjelm and Abucar, 2025), aiming to analyze the potential benefits and impacts of digitalization and automation systems on entry, loading, and exit processes at the Irish Ferries Ro-Ro terminal in Dublin Port (Pinna, 2023), investigating how communication issues arising from communication systems can be resolved by eliminating communication problems such as cultural and language differences that affect the monitoring of equipment through digitalization (Lidholm and Sjöberg, 2018) and assessing port digitalization levels (Yorulmaz and Baykan, 2024). There has been no previous research aimed at establishing a strategy for implementing digital transformation specifically for Ro-Ro terminals and no other research has applied the SWOT-FAHP Analysis method in this area. Considering these gaps in the existing literature, this study aims to make a significant contribution by addressing these gaps.

2. Conceptual Framework and Literature Review

2.1. Ro-Ro Transportation and Terminals in Türkiye

Türkiye serves as connecting Asia and Europe, holding a critical position in securely connecting major transportation routes, situated at the intersection of three continents. Moreover, the Suez Canal and the Strait of Gibraltar are vital for global transportation as important maritime chokepoints. Thanks to strategic location of

Türkiye has become an important country in terms of international maritime transportation.

The data in Table 1 argue that Türkiye's strategic position considerably enhances its commercial activities. Thanks to these structural advantages, maritime transport has a clear lead over other modes of transport in terms of import and export capacity.

Table 1. Türkiye's Foreign Trade by Modes of Transportation (2019-2022)

(Value: Million USD)

Mode of Transport	Exports				Imports			
	2019	**2020**	**2021**	**2022**	**2019**	**2020**	**2021**	**2022**
Highway ($)	54.461	53.127	68.749	78.879	37.177	41.883	48.896	59.446
Share in Owerall (%)	%30,1	%31,3	%30,5	%31	%17,7	%19,1	%18	%16,3
Seaway ($)	109.114	100.907	133.714	150.255	112.967	114.838	157.390	193.799
Share in Owerall (%)	%60,3	%59,5	%59,4	%59,1	%53,7	%52,3	%58	%53,3
Railroad ($)	971	1.287	1.648	2.460	1.447	2.144	2.891	2.968
Share in Owerall (%)	%0,5	%0,8	%0,7	%1	%0,7	%1	%1,1	%0,8
Airline ($)	14.849	12.732	18.735	20.686	29.238	39.260	26.057	38.581
Share in Owerall (%)	%8,2	%7,5	%8,3	%8,1	%13,9	%17,9	%9,6	%10,6
Other ($)*	1.436	1.581	2.366	1.892	29.514	21.389	36.189	68.917
Share in Owerall (%)	%0,8	%0,9	%1,1	%0,7	%14	%9,7	%13,3	%18,9
TOTAL	180.832	169.637	225.214	254.172	210.345	219.516	271.425	363.711

Source: Ministry of Trade, 2023.

In terms of cargo handling rates, Türkiye's 2022 figures show that the ports with the highest foreign trade volumes are the ports of Aliağa and İskenderun.

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These busy ports are of great importance in all areas, contributing significantly to regional and global economies. Ro-Ro terminals serve as extremely important logistics links in multimodal transport, as well as facilitating the transport of containerized and wheeled cargo. Due to these characteristics, they make transportation activities easier for the automotive industry, from the point of production to the end consumer. Although in the past they were used only for small-scale domestic/intercity transport, today they have become a globally accepted form of transport. With the increase in demand for maritime transport and political and legal incentives, they are gaining popularity in European Union countries and gradually increasing their capacity. The capacity of these ports and ships is also increasing in major manufacturing and trading countries such as China. In addition, safety concerns are rising due to negative incidents such as fires and collisions involving vehicles transported by ships, and maintaining safety standards in this mode of transport remains a challenging task (Li et al., 2023).

Türkiye benefits from the economic advantages provided by Ro-Ro transportation in its import and export activities (Şimşek et al., 2024). The air transportation's high cost and the increasing capacity in this mode of transport have led to the emergence of new routes (Başar et al., 2015). The Table 2 shown that more vehicles are arriving at and leaving Ro-Ro ports in Türkiye, which implies an increasing demand.

Table 2. Number of Vehicles Arriving at and departing from Türkiye's International Ro-Ro Ports (Between 2015 and 2023)

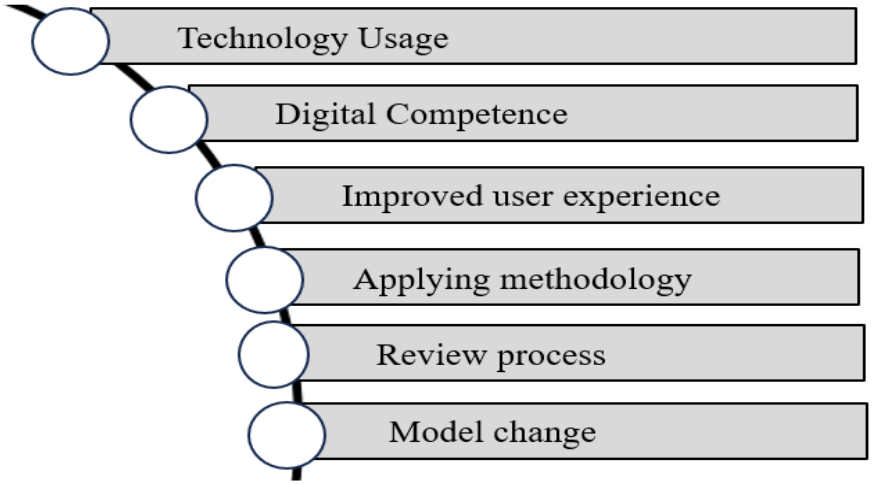
Years	Incoming	Outcoming	Total
2023	359.609	345.195	704.804
2022	357.592	361.996	719.588
2021	322.103	348.773	670.876
2020	244.797	259.955	504.752
2019	270.034	321.700	591.734
2018	255.691	327.869	583.560
2017	263.529	276.658	542.301
2016	230.996	241.354	472.350
2015	241.061	243.047	484.108

Source: Ministry of Transport and Infrastructure, (2023).

2.2. Digitalization and Digital Transformation

The terms "digitalization" and "digital transformation" derive from "digitus" and are occasionally used interchangeably across various sectors. These terms involve organizing and improving business processes by converting information systems into digital formats with various applications, software and leveraging the numerical data obtained (Klein, 2020). Digital transformation drives this development forward by making business processes, structures, models, and frameworks more effective through digital technologies (Ersöz and Özmen, 2020; I-Scoop, 2025). This transformation mostly involves automating systems that require more labor by combining them with today's technologies such as collected digital data and the Internet of Things. Businesses and industries that implement this transformation can gain advantages in terms of human resources, time, and cost by utilizing the benefits of developments that evaluate and shape digital data, such as artificial intelligence and cloud technology (Heilig et al., 2017; Sağlam, 2021; Sebastian et al., 2017). Technology and science are constantly evolving and offering new conveniences, so it has become extremely important to keep up with these innovations and incorporate them into businesses and the sector (André, 2019). As implementing technology-based changes in business processes is becoming increasingly critical to make competition sustainable, port operations, one of the most important elements of the maritime sector, also see digital transformation as an opportunity to be seized (Eyit, Yorulmaz, and Taş, 2022). Supporting port processes, coping with the competitiveness, and ensuring their sustainability depend on robust structures and the promotion of continuous innovation in the sector. Achieving this requires developing strategies for favorable funding, integrating logistics, attracting private sector investments, and ensuring compatibility with port systems. This situation requires strengthening market connections, fostering innovative business networks, and adopting Industry 4.0 technologies. The public and private sectors should focus these goals, guided by the six key factors outlined in Figure 1 (González-Cancelas et al., 2020).

Figure 1. Successful Digitalization Factors



Source: González-Cancelas et al. (2020).

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2.3. Literature Review

Today, transportation is the most important factor in global trade. Therefore, keeping up with technology is crucial for reducing costs in the sector and ensuring that operations are carried out more efficiently and with less risk. Ports, which are multimodal hubs connecting production and consumption, are increasingly at the forefront of digitalization by offering operational control and effective solutions throughout their entire processes (Inkinen, Helminen, and Saarikoski, 2021). The ease of access to raw materials and the delivery of goods from the point of production to the end consumer via sea transport have brought ports to the forefront of industry. Ports contribute to the economies of the regions and countries in which they are located, and consequently to growth. Therefore, preparation and design processes must be carried out meticulously to ensure the continuous provision of services related to handling, limbo, transport, terminal services, storage, and other types of transport (Baştuğ and Esmer, 2022; Çelik and Yorulmaz, 2025). Moreover, due to globalization, demand for ports in strategic regions of the world has increased alongside the rising demand for raw materials and products. The surge in demand is so substantial that it has led to the introduction of high-capacity vessels and the expansion of intermodal transport. Indeed, this trend is likely to continue in the upcoming years. Due to the swift growth of intermodal traffic, port managers need to upgrade their capacities and procedures to accommodate modern, high-capacity ships, which entails developing existing facilities and infrastructure. Nonetheless, not all ports can immediately carry out such substantial changes because of the high investment costs. As a result, ports are left with no choice but to enhance their port operations and cargo handling activities (Abourraja, Kringos, and Meijer 2022). Nguyen et al., (2022) investigated the quality of port services from the perspective of port users using FAHP and Importance-Performance Analysis to contribute to increasing their competitive capacity by referring to the economic value offered by ports.

Digital transformation helps companies adapt to changing environments, enhance resources, and streamline operations (He et al., 2023). Since the introduction of container transport in the late 19th century, information technologies have become critical for port competitiveness, significantly impacting operations, security, communication, and decision-making (Nikghadam et al., 2021; Panayides and Song, 2013). Adapting to new technologies requires port enterprises to align with top management's strategic vision for digitalization and transformation. Therefore, examining the factors influencing digital transformation in maritime transport also benefits stakeholders in designing their business models for digitalization (Jović et al., 2022). Illustration, González-Cancelas et al. (2020) analyzed the current state and determined strategies for Puertos del Estado, a port under the Spanish Ministry of Transport, aiming for Port 4.0 adaptation. They determined that it was crucial to assess the effective implementation of digitalization in the port sector and, consequently, its integration with logistics services before embarking on digital transformation and making investments towards it. They employed a SWOT analysis to manage the process. In their work,

Inkinen et al. (2021) examined the digitalization forecasts of Finnish ports serving the international trade and transport sector and applied the SWOT analysis method to evaluate the data obtained in their work. The study resulted in three recommended courses of action: firstly, digitalization requires continuous planning and foresight by port managers; secondly, professional solutions and standards are needed to guide the digitalization process; and finally, strategic foresight and implementation must be long-term (ten years and above). Seo, Lee, and Jeon (2023) used data obtained through a survey method from experts working at Busan Port (South Korea) to determine the fundamental digitalization strategies for the logistics cycle at container ports. To formulate the strategy, they prioritised 11 evaluation criteria using multi-criteria decision-making (MCDM) methods and concluded that access to information and quality could be improved through a sharing system.

Serra et al. (2021) examined the impact of modern technological communication resources and information systems on the transmission and operation of Ro-Ro terminal processes and investigated how the required systems and devices could improve these operations. Tsoukos et al. (2023), in their study investigating modern digital systems used to make port processes more efficient and sustainable, specifically for Ro-Ro terminals, examined a port management platform managed by automation-based cloud technology. Effectiveness was evaluated using existing information and advanced sensors. Trueba et al. (2022) suggested that improve the port's efficiency, operational growth, service quality, as well as competitive edge for examining the logistics service processes of a port. Their findings highlighted the prominence of digital transformation. In this context a review of the literature reveals that Ro-Ro terminals have been studied less than container terminals (Abourraja et al., 2023).

3. Methodology

This study aims to identify the factors influencing digitalization steps at Ro-Ro terminals in Türkiye, evaluate these factors, and develop digital transformation strategies accordingly. First, a literature review was conducted to identify the factors affecting the digitalization of Ro-Ro terminals, and SWOT matrices were created. Subsequently, the SWOT factors were examined by academics specialising in the field and Ro-Ro terminal managers, and the SWOT model was finalised. Afterward, a SWOT-AHP model was developed, and the SWOT criteria were prioritized by experts. Finally, strategies based on the SWOT matrix were formulated in line with the information obtained. The research model of the study is presented in Figure 2.

The components of the SWOT analysis method are four in number: Strengths (S), Weaknesses (W), Opportunities (O) and Threats (T). The SWOT method was selected for the research model because it has been frequently evaluated in the study conducted. SWOT analysis is seen as an approach for evaluating the internal and external factors that influence a unit or strategy to be adopted (Lee et al., 2021). However, the elements identified through SWOT analysis do not provide quantitative data that would allow numerical evaluation

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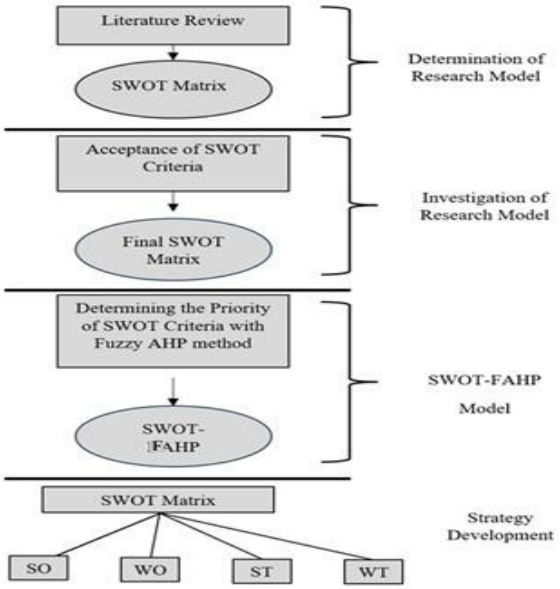
(Nguyen and Truong, 2022). To address this limitation, the literature shows that MCDM methods have been utilized.

Figure 2. Research Model



Source: Authors

In this context, the study employed the FAHP to partially determine the importance weights of SWOT analysis criteria. The SWOT criteria for identifying digitalization strategies in Ro-Ro terminals were obtained using the literature review method and interview forms (Abourraja et al., 2022; Abourraja et al., 2023; Branch, 1986; Develi, 2021; González-Cancelas et al., 2020; Jović et al., 2022; Lee et al., 2021; Inkinen et al., 2021; Nadeem et al., 2018; Sanchez-Gonzalez et al, 2019; Seo et al., 2023; Şimşek et al., 2024; Stopford, 2008; Trueba et al. 2022; Tsoukos et al., 2023; Varbanova, 2018; Yorulmaz and Baykan, 2024).

3.1. SWOT Analysis

The SWOT analysis, introduced in 1960 by Albert Humphrey as one of the strategic management tools, helps decision-makers reveal different options. The term “SWOT” stands for Strengths, Weaknesses, Opportunities, and Threats. SWOT analysis is an analytical method that can be applied in many different areas, even to individuals, by revealing the current situation. (Gurel and Tat, 2017). SWOT analysis, which helps scholars systematically identify and categorize internal and external factors, is a key assessment method in the strategic planning process (Bakır, Bal, and Akan, 2017).

While strengths highlight the positive aspects of the terminals, threats underline risks that can indirectly lead to adverse consequences for the port. Based on this foundation, suitable strategies are developed to leverage advantages and mitigate threats. Thanks to the SWOT matrix, managers can understand the challenges and develop strategies that consider the benefits and risks of digitalization in Ro-Ro terminals.

3.2. FAHP Method

The AHP method was developed in the 1970s, addresses MCDM problems (Saaty, 2004). FAHP is applied to make more precise decisions by listing the elements of preference and taking into account the uncertainty in the problems (Zolfani et al., 2012; Yürüyen & Ulutaş, 2020). In the AHP method, decision makers have to use numerical significance values between 1 and 9 in pair comparison matrices. But it may not always be possible to achieve clear results when dealing with real-life uncertainties. FAHP is useful as it allows decision-making through verbal explanations. Therefore, researchers in the literature preferred this method for their studies (Heo et al., 2010; Yürüyen & Ulutaş, 2020).

$X = \{x1, x2,...,xn\}$ can be a set of criteria, $U = \{u1,u2,...,um\}$ can be a set of goals. According to Chang's FAHP method, each criterion is taken, and rank analysis is applied for each goal. Thus, for each criterion, mmm rank analysis values are found as follows.

$$M^1_{gi}, M^2_{gi} \ ...,M^m_{gi}, \ i =1,2,...,n, \quad (1)$$

There $Mgi\ j$ (j =1,2,...,m) are all triangular fuzzy numbers. The steps of Chang's order analysis can be expressed as follows (Chang, 1996).

1: According to the i-th criterion, the value of the fuzzy synthetic order is as follows;

$$S_i = \sum_{j=1}^{m} M_{g_i}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j \right] (2)$$

$\sum_{i=1}^{m} M_{g_i}^j$ In order to find the expression; for a matrix, fuzzy addition is performed at m order analysis values.

$$\sum_{j=1}^{m} M_{g_i}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) (3)$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j = \left(\sum_{j=1}^{n} l_i, \sum_{j=1}^{n} m_j, \sum_{j=1}^{n} u_j \right) (4)$$

The inverse of the vector in Equation 4 is found as follows.

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j}\right] = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) (5)$$

2: $M2 = (l2, m2, u2)$ ³ $M1 = (l1, m1, u1)$ of the degree of likelihood is expressed as in the equation given in 7.

$V (M2\ M1)$ supëmin ($M1$ (x), M 2 (y)). (6)
and to be equivalent, it is as in the equivalence given in 8;

$$= \begin{cases} 1, if m_2 \geq m_1, \\ 0, if l_1 \geq u_2, \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} otherwise, \end{cases} \quad (7)$$

3: k fuzzy numbers of a convex fuzzy number Mi (i =1,2,.....,k) than the degree of likelihood that B is larger is expressed as follows;

$$\begin{aligned} &V(M \geq M_1, M_2, \ldots\ldots, M_k) \\ &= V[(M \geq M_1)\ and\ (M \geq M_2)\ and \ldots and\ (M \geq M_k)] \\ &= \min V(M \geq M_i), \quad i = 1,2,\ldots\ldots k. \end{aligned} \quad (8)$$

$d'(Ai) = \min V\ (Si\ ^3\ Sk)$, (9)
k =1,2,.......,n;k ¹ i The weight vector for the weight vector is as follows.
$W' = (d'(A1), d'(A2), \ldots\ldots\ldots, d'(An))T$ (10)
Here $Ai(i = 1,2,\ldots\ldots,n)$ is the number n.
4: The normalised weight vectors are as in equation 11;
$W = (d(A1),(A2), \ldots\ldots\ d(An))T$ (11)

W is a non-fuzzy number (Chang, 1996; Zhu, Jing and Chang 1999). While using Chang's FAHP method, the triangular fuzzy numbers given in Table 3 were utilized.

Table 3. Fuzzy Importance Levels

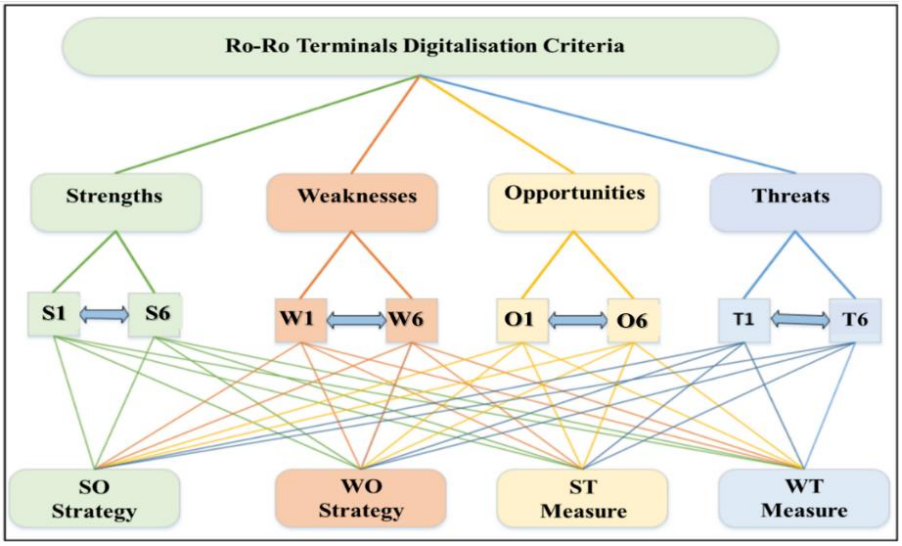
Verbal Importance	Fuzzy Scale	Reciprocal Scale
Equal importance	(1, 1, 1)	(1/1, 1/1, 1/1)
A little more important	(1, 3, 5)	(1/5, 1/3, 1/1)
Strongly significant	(3, 5, 7)	(1/7, 1/5, 1/3)
Very strongly significant	(5, 7, 9)	(1/9, 1/7, 1/5)
Totally important	(7, 9, 9)	(1/9, 1/9, 1/7)

Source: Authors

3.3. Integrated SWOT-FAHP

The SWOT analysis method enables the determination of an organizations or structure's current position, its evaluation, and ultimately, the reaching of a conclusion or decision. This method evaluates an organization's strengths, weaknesses, opportunities, and threats (Andrews, 1997; Yiğit and Demirbaş, 2020). The analysis aims to maximize the benefits from the organization's strengths and opportunities while minimizing or ideally eliminating the impact of weaknesses and potential threats (Shahabi et al. 2014; Yiğit and Demirbaş, 2020). However, the SWOT matrix alone does not quantitatively establish the weight of criteria, as it does not yield quantitative results. To address this limitation, SWOT analysis can be integrated with MCDM methods such as DEMATEL, VIKOR, and AHP (Sevim and Önder, 2020; Yiğit and Demirbaş, 2020). Some studies integrated with the SWOT analysis approach and the AHP for the MCDM method (Kurttila et al. 2000; Ergin, 2021). Indeed, Kurttila et al. (2000) also adapted a quantitative method for strategic decision-making and forecasting by integrating these two methods and converting criteria into measurable numerical forms. This integrated SWOT-AHP method has been applied across various sectors and developed the studies.

Figure 3. Ro-Ro Terminals Digitalization SWOT-FAHP Model



Source: Authors

In this study, the FAHP was utilized to address this gap in the SWOT analysis. The SWOT-FAHP scheme for this study is presented in Figure 3. Based on the findings from this analysis, growth strategies (SO, WO) are developed through the evaluation of strengths-opportunities and weaknesses-opportunities, while diversification strategies (ST, WT) are developed through the evaluation of strengths-threats and weaknesses-threats.

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4. Findings

The SWOT criteria (Table 4) were identified through a literature review and evaluated by expert port managers and academics according to a five-point Likert scale. Initially, there are a total of 71 criteria: 24 strengths, 17 weaknesses, 14 opportunities, and 16 threats. The criteria with the highest scores (3>) were selected to form the final SWOT criteria (Table 5). Subsequently, surveys were conducted among managers and information system specialists working in Ro-Ro ports to facilitate pairwise comparisons, transforming the criteria into fuzzy values using the importance scale presented in the study (Table 3). All calculations were performed in Excel at these stages. In the pairwise comparisons, the geometric mean of the values corresponding to the same criteria was calculated, and the expert evaluations were converted into a single fuzzy number. The average of these obtained numbers was primarily calculated using the geometric mean method commonly employed in the literature (Saaty, 2004). The evaluation of the criteria was conducted by a panel of seven experts, consisting of high-level managers in the maritime sector and academics in the field (2 academics, 2 operations managers, 1 general manager, 2 assistant managers, with educational backgrounds of 1 bachelor's degree, 2 master's degrees, and 4 doctoral degrees, averaging 20 years of experience in the sector and an average age of 43). The matrix generated from their evaluations is presented in Table 6.

Table 4. SWOT Matrix and FAHP Criteria

Strengths	**References**
S1. Operational management	Paulauskas et al., 2021
S2. Competitive Advantage	Branch, 1986
S3. High-level and low-risk handling	Branch, 1986/ Varbanova, 2018
S4. Cost Advantage	Varbanova, 2018
S5. Customer Satisfaction	Branch, 1986/ Varbanova, 2018
S6. Adaptation to multiple modes of transport	Branch, 1986
S7. Port operations require less personnel	Branch, 1986
S8. Providing transport services in a short time	Branch, 1986
S9. Organisation and process regulation for digitalization	Nadeem et al., 2018/ Yorulmaz and Baykan, 2024
S10. Sufficient capital for digital transformation	Paulauskas et al., 2021

S11. Adequate human resources	Paulauskas et al., 2021
S12. Increased confidence in transactions made on the internet	
S13. Information Technology infrastructure	Nadeem et al., 2018/ Yorulmaz and Baykan, 2024
S14. Connection with international maritime routes	
S15. Real-time digital data sharing	Paulauskas et al., 2021
S16. Open data	González-Cancelas et al., 2020
S17. Easy reaction to events	
S18. Use of technology in target identification	
S19. Uninterrupted observation ability	
S20. Use of artificial intelligence	
S21. Technological innovations	
S22. Operational capabilities	Paulauskas et al., 2021
S23. Use of digital solutions for port operations	Nadeem et al., 2018/ Yorulmaz and Baykan, 2024/ Paulauskas et al., 2021
S24. Digital transformation is carried out by academics and technology developers	Paulauskas et al., 2021/ Yorulmaz and Baykan, 2024

Weaknesses	**References**
W1. Insufficient human resources	Paulauskas et al., 2021
W2. Mismanagement	Paulauskas et al., 2021
W3. Level of integration with other transport networks	Develi, 2021
W4. High initial cost	González-Cancelas et al., 2020
W5. Specialised personnel and skills requirements	
W6. Difficulty of adaptation of employees to new tecno	
W7. Low capacity compared to container transport	Stopford, 2008
W8. Insufficient capital for digital transformation	Nadeem et al., 2018/ Yorulmaz and Baykan, 2024 / Paulauskas et al., 2021

W9. Lack of strategic planning compatible with digitalization	González-Cancelas et al., 2020/ Nadeem et al., 2018/ Yorulmaz and Baykan, 2024
W10. Impact of change in operations	González-Cancelas et al., 2020
W11. Control and monitoring of digital systems	González-Cancelas et al., 2020
W12. Old technological infrastructure	Paulauskas et al., 2021
W13. Inadequate port infrastructure	Paulauskas et al., 2021
W14. Difficulty adapting to unexpected situations	
W15. Larger storage needs	
W16. Interest in road transport in the country	
W17. Low productivity	Paulauskas et al., 2021

Opportunities	**References**
O1. Efficient and predictable supply chain	González-Cancelas et al., 2020
O2. Creating job opportunities	González-Cancelas et al., 2020/ Paulauskas et al., 2021
O3. Technology pursuit, adaptation and maturity	González-Cancelas et al., 2020/ Nadeem et al., 2018/ Yorulmaz and Baykan, 2024
O4. Expectation of economic growth with the use of modern technology	Paulauskas et al., 2021
O5. Impact of emerging markets and transport policy on ports	González-Cancelas et al., 2020/ Paulauskas et al., 2021
O6. Increased awareness to benefit from technology	Nadeem et al., 2018/ Yorulmaz and Baykan, 2024/ Paulauskas et al., 2021
O7. Increased efficiency in port operations through digitalization	Paulauskas et al., 2021
O8. Modern technology	Paulauskas et al., 2021
O9. Staff selection is in line with the digital strategy	
O10. Providing a variable and attractive environment for port employees	Nadeem et al., 2018/ Yorulmaz and Baykan, 2024
O11. Wheeled vehicle trade growth	Branch, 1986

O12. Low initial investment cost compared to other ports	Branch, 1986
O13. Opportunity to increase outsourcing	Paulauskas et al., 2021
W14. Digital transformation government and senior management support	Nadeem et al., 2018/ Yorulmaz and Baykan, 2024/ Paulauskas et al., 2021
Threats	**References**
T1. Lack of investment in employee training	
T2. Insufficient support policy against digitalization	Paulauskas et al., 2021
T3. Data security and piracy concerns	
T4. The risk of technology and machines displacing people from their jobs	
T5. Political and institutional risks	González-Cancelas et al., 2020
T6. Communication with other actors in the port sector	Nadeem et al., 2018/ Yorulmaz and Baykan, 2024/ González-Cancelas et al., 2020
T7. Changes in laws and regulations	González-Cancelas et al., 2020
T8. Vulnerability to cyber threats	González-Cancelas et al., 2020
T9. International financial uncertainty	González-Cancelas et al., 2020
T10. Decline due to not attracting highly competent employees	Paulauskas et al., 2021
T11. The country is located in an earthquake zone	
T12. Difference with other modes of transport	González-Cancelas et al., 2020
T13. Prejudice against new technologies	
T14. Decline in the transport industry affecting port information systems	Paulauskas et al., 2021
T15. Impact of time problems in port operations on the supply chain	Paulauskas et al., 2021
T16. Economic crisis and inability to outsource	Paulauskas et al., 2021

Source: Authors

Table 5. Final SWOT Matrix and FAHP Criteria

Strengths		**Weaknesses**	
S1	Operational management	W1	Difficulty in adapting employees to new technologies

S2	High-level and low-risk handling	W2	Insufficient capital for digital transformation
S3	Adaptation to multiple transport modes	W3	Lack of strategic planning compatible with digitalization
S4	Connection to international sea routes	W4	Control and monitoring of digital systems
S5	Operational capabilities	W5	Old technological infrastructure
S6	Use of digital solutions for port operations	W6	Difficulty in adapting to unexpected situations
Opportunities		**Threats**	
O1	Effective and predictable supply chain	T1	Lack of investment in employee training
O2	Creation of business opportunities	T2	Concerns about data security and piracy activities
O3	Technology tracking, compliance, and maturity	T3	Vulnerability to cyber threats
O4	Impact of emerging markets on transport policies for ports	T4	International financial uncertainty
O5	Increased efficiency in port operations through digitalization	T5	Impact of time issues in port operations on the supply chain
O6	Modern technology	T6	Economic crisis and insufficient use of external resources

Source: Authors

Table 6. SWOT-FAHP Analysis Weights and Ranking Results

SWOT Analysis Key Criteria Weights	Sub Criteria Weights	Sorting within itself	Total Ranking
W_S =0	W_{S1} =0,08627	5	18
	W_{S2} =0,0000	6	-
	W_{S3} =0,19853	3	11
	W_{S4} =0,26911	**1**	**6**
	W_{S5} =0,26166	2	7
	W_{S6} =0,18443	4	14
W_W =0,24343	**W_{W1} =0,33404**	**1**	**1**
	W_{W2} =0,23720	2	9

	W_{W3} =0,23683	3	10
	W_{W4} =0,00535	5	20
	W_{W5} =0,0000	6	-
	W_{W6} =0,18658	4	13
W_O =0,44939	W_{O1} =0,0000	6	-
	W_{O2} =0,0000	5	-
	W_{O3} =0,31816	**1**	**2**
	W_{O4} =0,11757	4	16
	W_{O5} =0,28855	2	3
	W_{O6} =0,27527	3	4
W_T =0,30718	W_{T1} =0,14051	4	15
	W_{T2} =0,09094	5	19
	W_{T3} =0,27498	**1**	**5**
	W_{T4} =0,18822	3	12
	W_{T5} =0,05845	6	17
	W_{T6} =0,24690	2	8

Source: Authors

According to Table 6, the connection with international maritime routes coded as S4 has the highest weight value among the strengths, while the high-level and low-risk handling coded as S2 has the lowest weight value among the strengths. Among the weaknesses, the difficulty of employee adaptation to new technologies coded as W1 has the highest weight value, whereas the old technological infrastructure coded as W5 has the lowest weight value. From the opportunities, the tracking of technology, compliance, and maturity coded as O3 has the highest weight value, while the effective and predictable supply chain coded as O1 and the creation of business opportunities coded as O2 have the lowest weight values. Among the threats, the vulnerability to cyber threats coded as T3 has the highest weight value, while the impact of time issues in port operations on the supply chain coded as T5 has the lowest weight value. Following the determination of the SWOT matrix, the factors can be organized into four pairs of strategy groups (SO, ST, WO, WT) (Yiğit and Demirbaş, 2020).

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Table 7. Ro-Ro Terminals Digitalization Strategy Matrix

Strategies Created	**Strong (S)**	**Weak (W)**
	Development Strategy (SO)	*Development Strategy (WO)*
Opportunity (O)	SO1-Adaptation to new technologies in the international arena SO2-To become more effective in international maritime transport by improving port operations through digitalization SO3- Technological co-operation with foreign parties in the sector SO4-To increase operational capability by using modern technology more effectively	WO1-To ensure the adaptation of employees to modern technology WO2-To pursue technology with less capital thanks to technologies such as autonomous and artificial intelligence WO3-To harmonise all planning with technology and digitalization WO4-Making port activities with less risk thanks to modern technology
	Diversity Strategy (ST)	***Development Strategy (WT)***
Threat (T)	ST1-Protecting operational capabilities against cyber attacks ST2-Minimising the impact of crises with the increase in efficiency achieved through digitalization ST3-Determining a road map for financial crises through current technologies ST4-To keep up with technological developments by following them closely	WT1-Training employees on technology to protect against cyber risks WT2-Plan more resources for digital transformation WT3-Protecting from financial uncertainties and planning outsourcing WT4-Making development plans in line with the digital strategy

Source: Authors

Accordingly, the strategy matrix developed for the digitalization strategies of Ro-Ro terminals is presented in Table 7. In developing this matrix, strategies for improvement were created by evaluating strengths and opportunities, diversity strategies by evaluating strengths and threats, and protection strategies by assessing weaknesses and threats.

5. Discussion, Conclusion and Suggestions

Maritime transportation, which plays a crucial role in global trade activities, and consequently ports, aim to continue their operations in an economic and sustainable manner amid increasing competitive conditions. As in every sector today, there is a growing need in the port industry to transform increasing data and complex information into meaningful forms while achieving the highest level of efficiency in their operations. To meet this need, ports have entered the search for leveraging digital technologies. In this period, which is often referred to as Industry 4.0, businesses want to harmonize their existing structures with digitalization in order to benefit more from digital technologies. However, since there are no

standards for these transformation processes and there is no roadmap suitable for the unique needs and structure of each sector, it is necessary to determine the digitalization processes. This study aims to identify the factors shaping the digitalization processes in Ro-Ro terminals in Türkiye, evaluate them with the SWOT-FAHP method. Thus develop digitalization strategies. For this purpose, it designs a SWOT matrix based on the evaluation of digitalization criteria determined by expert port managers and academics.

Based on the SWOT-FAHP method, this study identifies the strengths and weaknesses, opportunities, and threats associated with the digitalization of Ro-Ro terminals according to SWOT criteria. The results of the study indicate that the strengths are connections to international marine routes, operational capabilities, and the ability to adapt to multi-modal transport. The identification of increased operational efficiency and cost benefits are linked as a strength with improvements in the port's operational capabilities (González-Cancelas et al., 2020). For some researchers, weaknesses in this area include difficulties for employees in adapting to new technologies, lack of sufficient capital to drive digital transformation (Philipp et al., 2019), and lack of strategic planning aligned with digitalization (Hora et al., 2021; Alahmadi et al., 2022). The results of this study coincide with those of previous studies and support to literature (Demirel and Demir, 2024; González-Cancelas et al., 2020; Rabot et al., 2023). Key opportunities in the sector are technology tracking (Jiang et al., 2021), adaptability and maturity, and enhancing operational efficiency through digitalization (Inkinen et al., 2021; Almeida & Okon, 2024; Alahmadi et al., 2022) and modern technology (González-Cancelas et al., 2020). Among the main threats is vulnerability to cyber threats (Inkinen et al., 2021; Hora et al., 2021; González-Cancelas et al., 2020; Alahmadi et al., 2022), economic crises, insufficient outsourcing, and international financial uncertainties. In addition, the lack of similarity to other forms of transportation are seen as a threat (González-Cancelas et al., 2020). Indeed, Hora et al. (2021) stated that inadequate infrastructure, lack of qualified employees, and exposure to cyber threats are perceived as major threats, while inadequate management support for digitalization is considered a weakness. Moreover, creating a new workflow design is seen as an opportunity to gain a sustainable competitive advantage, while the existing hinterland is seen as a strength. It is recommended to consider these considerations in future design and strategy development efforts.

This study was conducted to determine the digitalization strategies for Ro-Ro terminals using the SWOT-FAHP method, some recommendations are listed below:

- To strengthen the strategic position by increasing the intercontinental transportation capacity by using the connection with international sea routes effectively.
- Invest in digital technology to enhance operational capabilities and improve efficiency in ports.
- To increase the use of digital systems and artificial intelligence in the planning of activities to be carried out with multimodal transportation.

- Plan training programs to make it easier for port workers to adapt from strategic management levels to information system operators and new technologies.
- Ensure that port managers' strategic decisions and planning align with digital transformation.
- Allocation More resources for modern digital technologies and digital transformation initiatives.
- Improving the efficiency of port operations Through digital transformation.
- Keep up with transportation innovations by following modern technologies.
- To take the necessary measures to mitigate or mitigate cyber risks, or effect.
- Provide that effective management of economic crises and financial uncertainties is achieved using digital technologies.

Ro-Ro terminals are an integral part of the maritime transport sector. Thus, this study contributes to theoretical and managerial for the important, both economically and socially. Given the industry's sensitivity to internal and external influences in an intensely competitive environment, it is vital to create targeted strategies that accurately identify these impacts and ensure the sustainable and efficient implementation of operational capabilities. Focusing on the digital transformation stages of Ro-Ro terminals, this study will expand the literature by focusing on the digital transformation stages of Ro-Ro terminals and laying the foundation for future research on this topic in the maritime sector.

It is known that the SWOT-FAHP method has been employed across different sectors, but there is no current research focused on the digitalization of Ro-Ro terminals with this approach. Therefore, this study is unique in that it addresses and fills a significant gap, even when digitalization in Türkiye's maritime sector is still in its early stages. Nonetheless, it has certainly its limitations, including the fact that the criteria were solely assessed by Ro-Ro terminal employees in Türkiye, and this limits the generalizability of the findings. Further research on this topic would expand the study by shedding light on the views of stakeholders from various regions or sectors involved in Ro-Ro transport. Furthermore, the lack of analysis on how digital transformation can increase the efficiency of Ro-Ro terminals is another limitation.

In the future, studies with various or mixed methods to study Ro-Ro terminals in Türkiye and all around the world are expected to expand the existing literature. Further research can involve comparative analysis of various port types, which can reveal whether digital transformation criteria differ by port category and reveal prioritized factors. This research would offer valuable insights for advancing digital transformation across the maritime industry.

AI declaration

The authors used Grammarly to edit the initial draft in English. They subsequently reviewed and revised the final draft and assumed full responsibility for the content of this publication.

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