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About the JEMS

Since 2020, JEMS has been published in English only.

Aim:

Journal of Eta Maritime Science (JEMS) aims to encourage and publish research studies about the challenges and opportunities associated with numerous numbers of understandings in maritime sector. Besides, JEMS also aims to reach out to relevant audience by publishing the studies covering latest scientific and technological developments. JEMS journal which is published periodically and regularly may also publish special issues related to the selected topics.

Scope:

Scope of the journal covers national, international and local studies regarding Marine Engineering, Marine Transportation Engineering, Naval Architecture Engineering, Marine Operations, Logistics, Logistics Engineering, Maritime History, Coastal Engineering, Marine Pollution and Environment, Fishing and Fisheries Technology, Shipbuilding and Ocean Engineering JEMS is indexed in Web of Science Emerging Sources Citation Index (ESCI), Tubitak Ulakbim Mühendislik ve Temel Birimler Veritabanı, Index Copernicus International, Directory of Open Access Journals (DOAJ), EBSCO.

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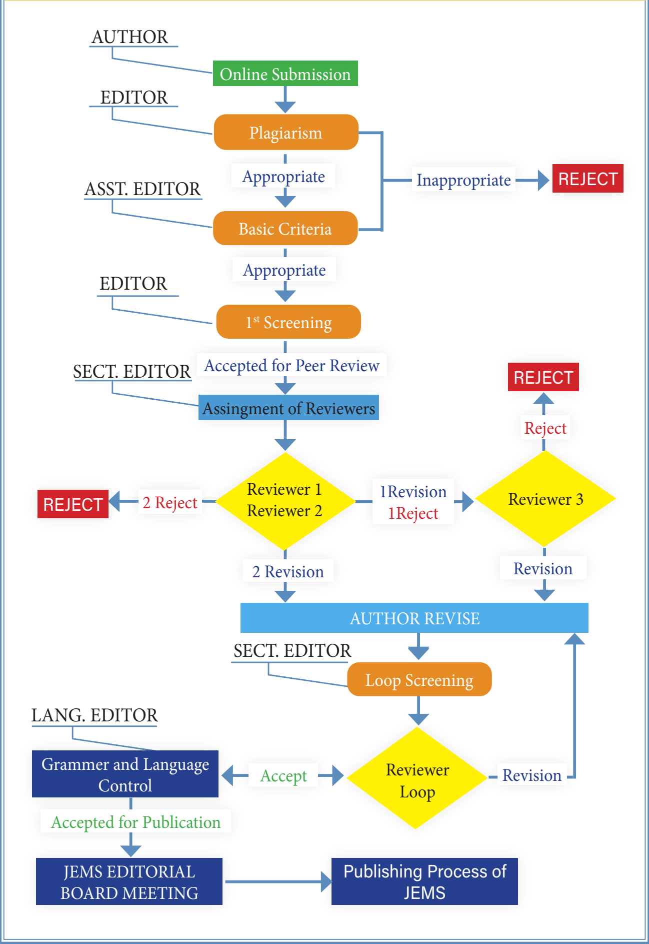

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Guide for Authors

Abstract

This sample includes the manuscript preparation guideline of Journal of ETA Maritime Science (JEMS). In abstract section a brief indicating the novelty and main findings of the study should be written. The text of abstract should be written fully justified, in italics and 10 pt. The section should be no more than 200 words. The number of keywords should be between 3-5.

Keywords: JEMS, Author, Manuscript, Guide

1. Introduction

Journal of Eta Maritime Science (JEMS) aims to encourage and publish research studies about the challenges and opportunities associated with numerous numbers of understandings in maritime sector. Besides, JEMS also aims to reach out to relevant audience by publishing the studies covering latest scientific and technological developments. JEMS journal which is published periodically and regularly may also publish special issues related to the selected topics. Scope of the journal covers national, international and local studies regarding Marine Engineering, Maritime Transportation Engineering, Naval Architecture Engineering, Marine Operations, Logistics, Logistics Engineering, Maritime History, Coastal Engineering, Marine Pollution and Environment, Fishing and Fisheries Technology, Shipbuilding and Ocean Engineering

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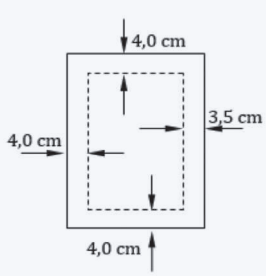

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The main title of article must be written in English and should be set centered in 12 point-size. Initially 6nk and after 6nk space should be left before the main title.

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1. 1 Axis Team

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Table 1. Sample Table

Turkish Male Seafarers (n = 131,152)	BMI < 25.0	BMI 25-30	BMI > 30	Number of Participants
16-24 Ages Group	74.1%	22.5%	3.4%	34,421
25-44 Ages Group	44.1%	43.3%	12.6%	68,038
45-66 Ages Group	25.6%	51.1%	23.4%	28,693
All Turkish Male Seafarers	47.9 %	39.6 %	12.5%	131,152
Turkish Male Population	47.3 %	39.0 %	13.7 %	-

In the article, decimal fractions should be separated with dots and numbers should be separated with commas.

Average age: 28.624

Number of participants: 1,044 people

Page numbers, headers and footers should not be added to the study. These adjustments will be made by the journal administration.

Authors are deemed to have accepted that they have transferred the copyright of their studies to the journal by submitting their studies to our journal. Submitting a study to two different journals simultaneously is not suitable within the frame of academic ethics.

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This is an article pertaining to the research compiled by summarizing researches and data which were previously carried out by other authors and/or institutions. (It cannot be accepted as an original research article) Title, Author, Abstract, Introduction, Literature Review, Conclusion, References (Maximum 6000 words, 15 pages).

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Book Review (BK)

This is an article where a newly published book concerning the maritime industry is evaluated in conformance with a certain methodology through an invited reviewer. (Maximum 1000 words).

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This is an article in characteristics of a compilation or a plain text where veteran academicians who are recognized with their academic knowledge and expertise would share their contributions in the field of maritime science, guide to young academicians and researchers and offer solutions for the demands of the maritime industry. (Invited by the editor).

Industrial Perspective

An article in conformance with a specified text format prepared by an expert as an invitee whose knowledge and experience related to their area of expertise is recognized to be beneficial by the industry (Invited by the editor). Title, Author, Abstract, Foresight about the subject, Results (Maximum 6000 words, 15 pages).

After the Meeting This article is written for the purposes of conveying the impressions, congress conclusion reports and information gathered during scientific conventions following a congress, conference and a symposium which is organized on such matters concerning the maritime industry. (Maximum 500 words).

5. References

The citation style used by our journal is Institute of Electrical and Electronics Engineers (IEEE) Reference Style.

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You can achieve the IEEE reference style and all reference examples used in our journal at https://jemsjournal.org/guide-for-authors.

JEMS Ethics Statement

JEMS Publication Ethics And Malpractice Statement

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EDITORIAL (ED)
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Journal of ETA Maritime Science 2021;9(1):1-2

A Brief Critique of the Year 2020 for the Maritime Industry

Selçuk Nas

Dokuz Eylul University Maritime Faculty, Department of Maritime Education and Training, Izmir, Turkey

Keywords

The COVID-19 pandemic, Maritime industry, Seafarers as the key workers

The year 2020 has been a difficult year for the maritime industry as much as it has been for all the world's industries. The Coronavirus disease-2019 (COVID-19) pandemic has caused changes in, and even the transformations of, many common maritime industry processes. We have seen the certifying of ships using remote inspection methods. We have seen the delivery of freight bill of lading to ships with the use of drones, signed and retrieved. We have witnessed the unprecedented isolation of seafarers who may not go ashore as authorities adopt the health safety policy of not entering ships. Such changes and transformations in 2020 are summarized below in terms of the affected main parties.

Seafarers. This has been the group most hit by the effects of the global restrictions imposed in the effort to contain the COVID-19 pandemic in 2020. IMO has declared seafarers as the key workers of the world in 2020 because despite the serious COVID-19-related difficulties and threats they faced, seafarers bravely continued to work to carry 85% of the cargo that humanity needed. Despite all these, however, the public has failed to perceive the important role played by seafarers in this pandemic and to accordingly bestow upon them the respect they deserve. While they face each new day with new rules, regulations, and restrictions, the world has largely left them unsupported and vulnerable to the disproportionate practices adopted by authorities. During this pandemic, seafarers have to contend with unjustifiable regulations, such as visa restrictions and flight bans that imprison them to their ships beyond the legal contract periods of convention.

Ship operators. During this pandemic, ship operators have also been adversely affected. In the midst of the discussions on how to implement the IMO Low Sulfur Regulation at the beginning of 2020, the sudden drop in oil prices combined with the pandemic voided the proposed Scrubber solutions, leading to the lifting of restrictions on ships to directly use low-sulfur fuels. This has resulted in the imposition of various measures designed to address the corrosion that developed from the use of chemicals designed to reduce sulfur content in fuel.

Ship owners. Presently, ship owners who are concerned about the commercial life of their existing ships must deal with Energy Efficiency Existing Ship Index (EEXI) values. Investors who want to order new ships will have to contend for a while with the uncertainties relating to new technological innovations and new fuel types that are designed to reach the target values of the IMO Green House Gas Strategy.

Maritime education. In 2020, a wave of "distance education" transformation hit maritime education following the implementation of pandemic-related constraints. These changes considerably affected conventional education methodologies, with lecturers needing to utilize very new remote access technologies in order to reach their students. Large capital infrastructures of maritime education institutions fell into disuse. Simulator-based training infrastructures were transformed and opened to remote access for the use of students. New solution strategies were developed. On the other hand, students could not complete their internship on board ship period because ships were inaccessible, which has delayed their graduation. Under such difficult circumstances, the UK Hydrographic Office extended invaluable support to world maritime education: the British executive agency made available their digital nautical publications to various maritime education institutions.

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JEMS. 2020 proved to be a successful year for JEMS such that new targets have been set. Firstly, we announced that the ETA Marine Science Journal (JEMS) was selected for inclusion in the Clarivate Analytics' platform Web of Science - Emerging Sources Citation Index (ESCI) database. Herein, we would like to thank the Web of Science Editors and the Journal Onboarding Team for their support. Secondly, we forged an agreement to obtain professional support from Galenos Publishing House with the assistance of our official publisher, the UCTEA Chamber of Marine Engineers. The difference this professional support makes is already apparent with the publication of the first issue for 2021.

Finally, we are pleased to introduce JEMS 9 (1) to our valued followers. This issue contains valuable and qualified research studies that would hopefully contribute to the betterment of the maritime industry. I would like to extend my gratitude to this issue's authors, our reviewers, our editorial board, our section editors and associate editors who ensure quality by diligently adhering to our publication policies. We would like to thank LookUs Scientific and Galenos Publishing House for putting in great efforts in the preparation of this issue.

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Digitalization in Container Shipping Services: Critical Resources for Competitive Advantage

Gökçay Balcı

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Abstract

The container shipping market has been transforming into a digital era, in which many operations and marketing facilities are being digitalized. Digitalization offers several benefits to container lines, such as performance improvement, efficiency, and better integration with suppliers and customers' effectiveness. The importance of digitalization is particularly appreciated during the Coronavirus disease-2019 disruption. However, a successful digitalization process requires several resources and capabilities that carriers and forwarders should exploit. It is still not clear what these resources are and which of them is more important. Accordingly, this study aims to identify and rank the critical resources necessary for a successful digital transformation of services to achieve a competitive advantage. Identification of the resources was done using the underpinning theory of resource-based view (RBV) of the firm and conducting interviews. This study then implements an analytical hierarchical process method to rank the relevant digitalization resources. The results indicate that the organizational and collaboration resources are the most important main resources, while the organizational culture for learning and innovativeness, integration of digital services, and collaboration with suppliers are the most important sub-resources. This study aims to contribute to the digitalization literature in the shipping industry by identifying and ranking critical resources within the perspective of RBV of the firm.

Keywords

Digitalization, Competitive advantage, Resource-based view, Container shipping, Digital transformation

1. Introduction

Global competition has been increasing day by day and achieving a competitive advantage is one of the fundamental aims of the companies. Firms need to deliver superior value to their customers to sustain their competitiveness. Philip and Gary [1] emphasize the importance of creating competitive advantage and consider it as the extension of marketing. Porter [2] suggests that the right utilization of technology is considered as a source of creating competitive advantage. Day [3] also indicates the creative use of information technology as one of the dynamic capabilities that firms need to have if they are to be market-driven. In today's competitive business environment, digitalization is the key enabler for value creation [4].

Maritime transport plays a significant role in international trade as over 80% of the cargoes, in terms of volume, are carried by sea. Container shipping, in which mostly finished and semi-finished products are transported, has been a significant enabler of international logistics alongside bulk vessels carrying vital raw materials, such as iron ore and coal, which is the key to deliver customer value globally [1]. Despite its vital role in international trade and logistics, the container shipping market has been facing turbulent times in recent years due to the low profitability rates and increased competition. Differentiation has also become more challenging due to strategic alliances between shipping lines [5]. On the other hand, the expectations of shippers and forwarders, i.e., customers of the container lines, are getting more demanding and complex due to increasing global competition and advancing consumer demands [6]. Hence, creating value, and thereby achieving competitive

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advantage have become crucial for container lines to survive in such a dynamic environment.

The digitalization of services is considered to be a vital source for the differentiation and competitive advantage in logistics services [7]. The literature indicates numerous benefits of digitalization and information technologies (IT) in the logistics and freight transport industry. For instance, Lam and Zhang [8] applied a quality function deployment method in the liner shipping industry and found that the dimensions of digital innovative solutions have a significant impact on customer value. Similarly, Poulis et al. [9] also suggested that a digital transformation in shipping can enhance the value among ecosystem members. The effective utilization of IT can help logistics firms achieve efficiency and increase their performances in reverse logistics [10], enable them to innovate [11], and achieve sustainability [12]. Digitalization may help minimize the barriers in the application of intermodal transportation [13]. Digitalization also plays a key role in the improvement of performance and inter-organizational relationships in land-sea supply chains [14], which is crucially important considering the increasing attention by the container lines on door-to-door services.

Besides the proven advantages of the digital transformation in the shipping and logistics market, shipping lines are also surrounded by pressures for digitalizing their services. This has become especially evident in the Coronavirus disease-2019 (COVID-19) pandemic process. Digital solutions offered by companies have been helpful in the continuation of supply chains. For instance, some courier services were disrupted due to lockdown measures in the beginning of the COVID-19 pandemic and many importers were not able to release their cargoes from ports as they could not get the printed bills of ladings. For non-negotiable bills of ladings, electronic seaway bills allowed shippers to avoid this disruption and continue their logistics operations. Similarly, online bookings helped shippers to sustain and carry out shipments smoothly. In line with this, several container lines have reported that their online booking tools have been used significantly more than the pre-pandemic period. Apart from the disruptions such as COVID-19, global supply chains have started to put more emphasis on the traceability of their shipments. The increase of investments in last-mile deliveries and the boost in the fast fashion market have led to sensitivity in traceability. Supply chains such as Zara and IKEA are also investing a lot in their digital transformation, which could only be achieved if shipping companies also transform their services into a more digital format. The recent examples of digitalization in container shipping include online bookings, online freight quotations, digital documentation, real-time tracking, and live chat customer services [15]. These services might be implemented through the traditional web and electronic data interchange applications or through more advanced recent technologies such as blockchains and internet-of-things (IoT). Digitalization may also involve autonomous operations such as unmanned vessels but this will not be covered in this paper [9].

There exist remarkable potential benefits of digitalization and several application areas in container shipping. Some of these digital solutions have already been applied by the leading global container lines. However, the successful implementation of digital products in container shipping services depends on several factors, and the companies that offer these services should be aware of these factors. For instance, Vogelsang et al. [16] indicated that there are three dimensions of critical success factors in the digital transformation of a manufacturing company: collaboration, technology, and the environment. Technology and environment, together with organization and cost factors, were also emphasized by Yeh and Chen [17] who investigated the success factors of 3d printing adopted by Taiwanese manufacturers. Cichosz et al. [18] investigated the success factors of the digital transformation in the logistics industry and identified eight different facets such as leadership, process standardization, employee training, skills development, and leveraging internal and external knowledge. Since the logistics industry usually lags behind others such as banking in terms of digitalization, it is of critical importance for container lines to pay attention to these factors [18].

It is of significant importance that container shipping lines should understand the factors affecting the successful implementation of digital services. More importantly, they should figure out which resources play a more important role in the digital transformation of services. This is vital as the resources of the companies are heterogeneous in the market [19]. Despite the existence of some articles investigating the success factors of digital transportation in related areas, the subject has not been studied sufficiently in the shipping context. Besides, very few studies have attempted to find out the importance degree of these factors. Moreover, to the best knowledge of the authors, no study in the shipping domain has approached this problem with a resource-based view (RBV) and employs the ranking of critical resources necessary for the digital transformation. Accordingly, this paper aims to identify and rank the critical resources for the successful implementation of digital services to achieve a competitive advantage in container shipping. The theoretical lens of the research is underpinned by a RBV and applies an analytical hierarchy process (AHP) methodology to rank the critical resources. The paper also presents implications to both literature and practice in the discussion section.

2. Literature Review and Theoretical Background

The theoretical background of this study is underpinned by a RBV. RBV is a competitive advantage theory that posits that firm resources and capabilities are heterogeneous and suggests that the resources of a firm are the key sources for achieving and sustaining a competitive advantage [19,20]. The theory proposes that it is the resources and not the products that give edge to firms in regard to competitive advantage. Resources may involve brands, personnel, machinery, financial assets, procedures, know-how, business relations, and many different tangible and intangible assets as well as processes. The RBV theory postulates that the resources of firms should be valuable, rare, inimitable, and non-substitutable to be able to achieve a competitive advantage.

The theory has been widely acknowledged and utilized in different aspects of business strategy. Maritime transport literature has also used the RBV theory to anchor the theoretical basis of studies. The theory has been utilized in the supply chain integration in container shipping [21], sustainable shipping management [22], logistics performance in the shipping industry [23], and several other topics such as innovation capabilities of shipping lines, the competitive advantage of ports, and market orientation [24]. In terms of digitalization in shipping, very few papers have adopted the RBV theory to justify the theoretical background of the study [25].

The RBV theory suits very well to explain the theoretical background of this research as well. The competition among container lines as well as freight forwarders is getting fiercer day by day. Container lines particularly have been suffering from low profitability rates in recent years. They have ordered mega vessels to reduce their unit costs and have signed strategic alliance membership contracts to fill the capacity of those mega vessels and operate them more efficiently. However, these cost reduction and operational efficiency measures have not been sufficient to let them increase their profitability rates [26]. They need to differentiate themselves from other lines and create value for their customers to gain a competitive advantage [5], which can be achieved through the digitalization of services they provide [27]. In parallel to the groundings of the theory, it is observed that the container shipping market is heterogeneous [26]. It is not only heterogeneous of customers but also the resources of the container lines, since a notable gap exists between the container lines in terms of digitalization of services.

RBV is also a very appropriate theory for this paper as the main aim is to investigate the internal resources of container lines at the firm level. Successful implementation of digitalization can be possible as long as different resources are utilized effectively. These resources do not have to be tangible, such as information technology equipment, but also include the intangible ones, including organization skills and customer orientation capabilities. As indicated in the study of the adoption of blockchain in the supply chain using RBV by Latha et al. [28], a successful implementation of digitalization also requires the collaborations among the suppliers, customers, and other branches. RBV is also an appropriate theory regarding the explanation of collaboration capabilities.

The literature in shipping digitalization is limited and ample space exists to fill in this area. Among the few studies conducted about digitalization in shipping, Lambrou et al. [25] conducted a qualitative study and discussed several digitalization applications in the shipping industry, such as IoT, blockchain, and artificial intelligence. The authors listed the drivers of digitalization in shipping as process improvements, cost efficiency, customer and business partner expectations, data monetization models, radical innovations, market share, innovation push, and institutions. Vaio and Varriale [14] studied the sea-land supply chain in the port operations in the Italian context. They investigated digital platforms on the business process of seaport organizations and indicated several benefits of digitalization such as paper reduction, cost reduction, quick access to information, and reduction of errors in information sharing. Poulis et al. [9] conceptually discussed how digital transformations in shipping would create value in the industry. The focus of the paper is the automation of unmanned vessels.

One of the recent digitalization trends in the shipping literature is the application of blockchain technology and smart contracts. Blockchain offers great opportunities for the digitalization of procedures such as customs clearance and documentation, even including the original bill of ladings. Yang [27] conducted a survey study about the blockchain application on Taiwanese maritime stakeholders, indicating that the customs clearance, digitalizing and easing paperwork, and the standardization and platform development positively influence the intention to use the technology. Bavassano et al. [29] also critically discussed the application of blockchain in the shipping industry and stated that the regulators and public authorities present the main barrier to the application. Pu and Lam [30] also conceptually discussed the adoption of blockchain in the shipping industry. These recent studies in shipping digitalization present great value to the literature. However, the digitalization of services, such as bookings and freight quotations, are not discussed in detail in the literature. Particularly, how these digital services can be successfully implemented is not studied.

Borrowing the success factors of the digital transformation literature in other industries may help us deduct some understanding on the topic. Liu et al. [31] investigated the resources fit for the digital transformation with an application in e-banking services. The authors have divided the resources and capabilities into four by sorting both dimensions as internal and external. The study revealed that the most important external resources are the historical path and embedded trust, while a dedicated liaison device and a highly authorized team are the most important internal resource fits required. The study also found that the most important external capability fits are collaboration and customization, while IT integration and reconfiguration ability are found to be the most important internal resource fits required [31].

Vogelsang et al. [16] studied the success factors for fostering digital transformation in manufacturing companies. In their results, the success factors consisted of three main dimensions: Organization, environment, and technology. The organization dimension involves 10 variables such as autonomy, employee qualification, culture, management support, and usability. Meanwhile, the environment dimension encompasses connectivity, collaboration, transparency, standards, and hybrid value creation. The technology dimension, on the other hand, involves infrastructure, reliability, adaptability, security, and completeness. Another recent study [32] studied digital servitization and identified some management initiatives such as engaging internal and external stakeholders, establishing digital service centers, focusing on customer value, and changing the employee structure.

3. Methodology

This study aims to identify and rank the importance of critical resources for the successful digitalization of services to achieve a competitive advantage in container shipping services. Accordingly, the study first identifies the critical resources for digitalization in the literature review. Qualitative interviews are then conducted with experts in the container shipping industry to validate the content and appropriateness of the variables identified in the literature. After, an AHP survey, which is the main methodology in the paper, is conducted with experts working in the container shipping industry.

This study has implemented AHP to find out the importance weight and ranking of critical resources for the successful digitalization of services in the container shipping market. AHP is a "theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales" [33]. AHP method simplifies complex problems by involving the judgments and experience of experts in the context of the problem. In AHP methodology, the decision makers are able to use their objective and subjective judgments. AHP has been implemented in many different research areas owing to its easiness in use and ability to handle multiple criteria whether they are qualitative or quantitative [34]. The AHP method has been applied by many studies in selection problems between alternatives, but it has also been widely used to determine the weight importance and ranking of a set of criteria without a selection of an alternative [35]. For instance, the method has been used by several studies to identify critical success factors or barriers in the implementation of a service, competition, and adoption of a new strategy. Several examples exist within the domain of shipping and digitalization literature as well [36-39].

The AHP methodology consists of eight steps in our study. First, the goal of the research is determined, which is the ranking of the critical resources of companies for successful digitalization of services in the container shipping market for this paper. The second step is to determine the criteria and create a hierarchical structure. As for the critical resources, five main resources (main criteria) are identified from the literature review and expert interviews as shown in Table 1: organizational, technological, reputational

Table 1. *Critical resources for digitalization of services to create a competitive advantage in container shipping*

Main criteria	Sub-criteria	Sources
Organizational resources	• Support from top management for digitalization • Knowledge/experience of employee in digital services • Organizational culture for learning and innovativeness	[16,18]
Technological resources	• IT infrastructure of the company • Investments for cybersecurity • Integration of digital services	[17,31]
Reputational and power-related resources	• Brand reputation of the company • Financial strength of the company • Global presence and connections	Interviews
Collaboration resources	• Collaboration with customers in digital service development • Collaboration with suppliers in digital service development • Collaboration with other branches and regions in digital service development	[16]
Market orientation resources	•Value creation strategies for customers • Strategies for customer satisfaction • Commitment to service quality	[40] and Interviews

IT: Information technologies

and power-related, collaboration, and market orientation resources. Each of the main criteria has a total of three sub-criteria. Interviews for identifying the critical resources were conducted with five managers who have at least 10 years of experience (three from container lines and two from freight forwarders). Purposive non-probabilistic sampling has been utilized to ensure that respondents are correct people to evaluate the appropriateness of variables utilized in AHP method. These interviews were conducted over Zoom online meetings in July 2020 and lasted between 25-40 minutes. The interviewees were asked to comment on the list of the critical resources identified from the literature review. They agreed with the content of the critical resources and also added one more main resource with three sub-resources.

The third step of the AHP is to construct a pairwise comparison matrix using a 9-point scale as suggested by Saaty [33]. Table 2 illustrates the AHP survey that is created by designing 9-point scale comparisons.

The fourth step of the AHP is to collect the data. This study has adopted a judgmental sampling method. The respondents are carefully selected through the LinkedIn social network by considering their positions and role in the companies. Although the container shipping's ecosystem involves several members such as shippers, terminal operators, port authorities, and customs, this research has focused on the freight forwarders and container lines. Container lines are the main providers of container shipping services and have also been recently transforming their operations digitally. Freight forwarders are the customers of container lines and are also the freight transportation providers for shippers. Thus, they are both the users and suppliers of the digital services in a shipper's perspective. Experts with a managerial working level these types of companies are targeted for the sampling. Twenty-six experts have responded to the survey. Fourteen of these respondents comprise of container lines and 12 of them are freight forwarders. All the selected experts are at a managerial level and have at least 10 years of container shipping industry experience with an average of 15 years. The experts are located in Turkey.

Table 2. *AHP scale*

Intensity of importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Values in between
AHP: Analytical hierarchy process Source: Adopted from [33]	

The fifth step is to create a pairwise comparison matrix. However, before creating a pairwise comparison matrix, it is important to take the geometric mean of each respondents' final ratings [33,41]. We let the criteria be a1, a2, ..., an and the weights be w1, w2, ..., wn. Thus, after taking the geometric mean of the experts' opinions, the pairwise comparison matrix for the 5 criteria is shown below.

$$A = \begin{bmatrix} 1.00 & 1.98 & 1.52 & 0.62 & 1.31 \\ 0.51 & 1.00 & 1.12 & 1.09 & 1.11 \\ 0.66 & 0.89 & 1.00 & 1.35 & 1.03 \\ 1.61 & 0.92 & 0.74 & 1.00 & 1.76 \\ 0.76 & 0.90 & 0.97 & 0.57 & 1.00 \end{bmatrix}$$

The sixth step of the AHP is to estimate the relative weight of the elements with the utilization of the following formulas. a_{ij} becomes $\frac{1_{ji}}{a_{ji}}$ because of the reciprocity feature. Similarly, a_{ij} becomes $\frac{a_{ik}}{a_{jk}}$. In real problems, the result of the equation of $\frac{w_i}{w_j}$ is unknown. Thus, in AHP, the a_{ij} value is expected to be calculated [42]. The demonstration of the normalized matrix is shown below.

$$W = \begin{bmatrix} 0.22 & 0.35 & 0.28 & 0.13 & 0.21 \\ 0.11 & 0.18 & 0.21 & 0.24 & 0.18 \\ 0.14 & 0.16 & 0.19 & 0.29 & 0.17 \\ 0.36 & 0.16 & 0.14 & 0.22 & 0.28 \\ 0.17 & 0.16 & 0.18 & 0.12 & 0.16 \end{bmatrix}$$

After calculating the normalized matrix, the priority vector is then obtained.

$$w = \begin{bmatrix} 0.24 \\ 0.18 \\ 0.19 \\ 0.23 \\ 0.16 \end{bmatrix}$$

To calculate the priority matrix, A and *w* values are multiplied.

$$A.\,w = \begin{bmatrix} 1.00 & 1.98 & 1.52 & 0.62 & 1.31 \\ 0.51 & 1.00 & 1.12 & 1.09 & 1.11 \\ 0.66 & 0.89 & 1.00 & 1.35 & 1.03 \\ 1.61 & 0.92 & 0.74 & 1.00 & 1.76 \\ 0.76 & 0.90 & 0.97 & 0.57 & 1.00 \end{bmatrix} \begin{bmatrix} 0.24 \\ 0.18 \\ 0.19 \\ 0.23 \\ 0.16 \end{bmatrix} = \begin{bmatrix} 1\ 24 \\ 0\ 94 \\ 0\ 98 \\ 1\ 20 \\ 0\ 82 \end{bmatrix}$$

The seventh step of the AHP method is to calculate the eigenvalue (λ) by dividing the priority matrix to the priority vector.

$$\lambda = \begin{bmatrix} 5.17 \\ 5.18 \\ 5.20 \\ 5.21 \\ 5.18 \end{bmatrix}$$

The eighth step of the AHP method is to calculate the degree of consistency ratio (CR) to mainly ensure the consistency of subjective perceptions and the accuracy of relative weights [33]. However, the first consistency index (CI) must first be calculated using the formula 1 below:

$$CI = \frac{(\lambda \text{Maks} - n)}{(n-1)} = \frac{(5.19-5)}{4} = 0.0468 \quad (1)$$

Where λ_{Maks} is the average value of each λ value and *n* is the number of criteria. The CI value must be equal to or lower than 0.1 to reach a reliable result [42]. CR is then calculated using the following (formula 2) .

$$CR = \frac{CI}{RI} = \frac{0.0468}{1.12} = 0.0418 \quad (2)$$

Where resistive index (RI) means random inconsistency index. RI is the average inconsistency calculated by the randomly generated matrices for the same dimensions. The most commonly used RI values are proposed by [33] and shown in Table 3.

Since the CR value is lower than 0.1, this means that a consistency occurs between the experts' responses [42]. Thus, all priority matrix values are considered as the weights of the criteria. To calculate the weight of the sub-criteria, the same calculations are conducted.

4. Results

Table 4 illustrates the results of the AHP analysis. Among the main criteria, the most important criterion is the organizational resources, followed by the collaboration resources. The weights of these two criteria are quite close to each other. The third most important resource for achieving competitive advantage in digital transformation is reputational power, followed by the technological resources. On the other hand, the least important main criterion is market orientation. Considering the weight of the main criteria, there is no remarkable gap between the main resources. Only the organizational and collaboration resources have relatively higher importance compared to the other three resources. Market orientation resources may also be the least important one, but its importance weight is almost 16%, which cannot be overlooked.

It is necessary to examine the importance of the global weights and rankings of the sub-criteria to reach more refined results. This is important because not all sub-

Table 3. *RI values proposed by Saaty [33]*

	Matrix dimension (n)								
	3	4	5	6	7	8	9	10	11
RI	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

RI: Resistive index

Table 4. *AHP results*

Main criteria	Weight	Rank	Sub-criteria	Local weight	Local rank	Global weight	Global rank
Organizational resources	0.239	1	Support from top management	0.335	2	0.080	4
			Experience of employee in digital services	0.213	3	0.050	12
			Organizational culture for learning	0.451	1	0.107	1
Technological resources	0.182	4	IT infrastructure	0.347	2	0.063	9
			Investments for cybersecurity	0.141	3	0.026	15
			Integration of services	0.520	1	0.095	2
Reputational and power resources	0.189	3	Brand reputation of the company	0.403	1	0.076	6
			Financial strength of the company	0.302	2	0.057	10
			Global presence and connections	0.295	3	0.056	11
Collaboration resources	0.231	2	Collaboration with customers	0.339	2	0.078	5
			Collaboration with suppliers	0.363	1	0.084	3
			Collaboration with other branches	0.297	3	0.069	8
Market orientation resources	0.158	5	Value creation strategies	0.448	1	0.071	7
			Strategies for customer satisfaction	0.238	3	0.038	14
			Commitment to service quality	0.313	2	0.049	13

AHP: Analytical hierarchy process, IT: Information technologies criteria have the same level of importance within the main criterion. Accordingly, the most important three sub-criteria in order are the organizational culture for learning and innovativeness, integration of digital services, and collaboration with suppliers. Support from the top management for digitalization, collaboration with customers for digital service development, and the brand reputation of the company are also relatively more important compared to the rest of the criteria. The least important criterion is the investments for cybersecurity, while the second and third least important criteria in order are the strategies for customer satisfaction and the commitment to service quality. Compared to the main criteria, the weight gap between the most important and least important resources is relatively higher among the sub-criteria.

Considering the overall results, organizational resources are found to be the most important main resource, while organizational culture for learning is found to be the most important sub-criterion under this resource. Collaboration resource is ranked as the second most important, while the collaboration with suppliers is ranked as the most important sub-criterion in this resource. The reputational and power resource is ranked as the third most important main criterion, while brand reputation is the most important sub-criterion in this main criterion. Technological resources is the fourth most important criterion, while the integration of services under this category is the most important sub-criterion. Finally, the market orientation resources is the least important main criterion in the research, while the value creation strategies are found to be the most important sub-criterion under this criterion.

5. Discussion

The purpose of this study was to identify and rank the critical resources for the successful implementation of digital services to achieve a competitive advantage in container shipping. A total of five main criteria and 15 sub-criteria were identified based on the literature review and expert interviews. Overall, the respondents believe that the most important sub-criterion is the organizational culture for learning and innovation, which is not surprising as digitalization is a significant transformation of the manual services and operations, which are complex and critical procedures in container shipping. Hence, it requires constant learning of employees that can be achieved by an innovative culture that attaches importance to learning. The necessity of constant learning may also be the reason why this sub-criterion is more important than the other two under organizational resources, which are support from top management and experience of employees in digital services. If employees are not experienced in digital services or no sufficient support is received from the top managers, an organizational culture for constant learning can help the improvement of the other two sub-criterion as well.

It is also not surprising to see that the integration of digital services is the second most important resource. Shipment of a container from its origin to the final destination compels multiple discrete steps. The integration of these separated steps would create a significant value for users. The integration of digital services, such as booking submissions and empty container releasing, would help shippers and forwarders gain a significant amount of time and reduce the possibility of mistakes. Results of the study indicate that a successful implementation of the digital transformation also demands a collaboration with the suppliers, customers, and other branches. This result is logical as the container shipping market often involves close relationships among the industry's members. Particularly, the relationship among the forwarders, container lines, terminals, and lines are very profound. Therefore, it is not surprising to see that the respondents believe that collaboration is an important resource for the successful implementation of digital services to achieve a competitive advantage. The collaboration between ports, lines, forwarders, and shippers allows the successful implementation of digitalization. Similarly, the implementation of a successful digitalization can also enhance the integration and cooperation of these stakeholders more effectively and efficiently, as indicated in previous literature as well [13,14]. The elimination of unnecessary paperwork and the reduction of excessive procedures that need to be approved in a non-automated way such as container releasing can better help in the integration of these stakeholders.

The experts in the AHP survey found market orientation resources as the least important main resource. Within this main resource, value creation strategies are considered to be ranked as 1st in local and 7th in global ranking among 15 criteria. The strategies for customer satisfaction and commitment to service quality are found to be the 14th and 13th ranked resources, respectively. This might be because the experts are not able to relate these criteria to digital transformation, which is usually considered more like an operation or information technology rather than a part of marketing. Although marketing theoretically encompasses digitalization and other processes that add value to customers, it may not be reflected in the same way in practice. Value creation strategies seem to have a more explicit and direct relation to digital transformation, which may be the reason why it is ranked 7th in global rankings.

The findings of the study have some similarities with the previous literature. Our findings are parallel with [31] who reported the collaboration and integration as the most important resources and capabilities in the digital transformation of e-banking. Our results are also in line with [16] where the authors found that a successful digital transformation can be achieved only if the provider collaborates with the suppliers and customers. Moreover, they also emphasize the necessity of change in the organizational culture to adapt to a more digital environment. Our results are also in line with [18] that particularly underlines the importance of creating a supportive organizational culture for digital transformations in logistics service providers. However, this study's results are not in parallel with [17] that reported the organizational factors as the least important resource in 3D printing adoption. This dissimilarity may be due to the difference in the topic, industry, and the region where the study was conducted.

6. Conclusion

This study has investigated the critical resources necessary for digitalization in container shipping to create a competitive advantage. Organizational resources and collaboration resources are found to be the most important, while market orientation resource is the least important success factor. Other main criteria involved in the study are the reputational and power resources, technological resource, and market orientation resources. Among the sub-criteria, the organizational culture for learning and innovativeness is found to be most important criterion. The collaboration with suppliers and the ability to integrate digital services are the second and third most important sub-resources, respectively. Digitalization has numerous benefits to the container shipping industry but the process of digital transformation is challenging. This study may help the companies to focus on relatively more important resources to achieve a competitive advantage in their digitalization journey.

This study contributes to the literature by being the first research paper (to the best knowledge of authors) investigating the critical resources required for successful digitalization of services to achieve a competitive advantage in container shipping. This is quite timely as the digitalization literature in shipping has been receiving more emphasis in recent years [14,25]. This study can help authors consider a variety of different resources while conducting their digitalization studies in the shipping domain. The results also open a significant avenue for future studies. For instance, a study using structural equation modeling or a multiple regression analysis can be applied to test the impact of the perceived performance in the critical resources on the overall relative digitalization performance and perceived user satisfaction. Whether these resources are reflected on the perceived usefulness of users remains a question.

The study contributes to theory by confirming the propositions of the RBV because the findings of this study are also aligned with the RBV of the firm. Although the integration of digital services is found to be the second most important sub-resource, technological resources is the fourth important main resource. The low rank of technological resources might be surprising at first but will make sense considering a RBV. The RBV suggests that the companies can achieve competitive advantage only if the resources are imitable. IT infrastructure and investments in cybersecurity are crucial to implement digital services. However, these resources are not imitable and can easily be replicated by competitors. On the other hand, the ability to offer integrated digital services is not imitable as it requires know-how, market knowledge, teamwork, and a great coordination among different departments, suppliers, and customers. These elements are of significant importance to digital transformation but are also difficult to replicate by competitors. This is probably why the respondents ranked this as the second most important resource. Similarly, creating a learning and innovative culture, collaboration with suppliers and customers, and brand reputations are not easy to imitate.

There are also practical implications for container lines and other service providers in the container shipping market. First, all the main resources are shown to somehow play important roles in digitalization. Thus, none of the resources in this study can be overlooked by the container lines. However, rather than focusing only on the product development and investing in IT infrastructure and cybersecurity, this study reveals that the most essential task is to transform the organization into a learning and innovative one. This of course requires a long-term dedication for the companies. Creating such culture would help the container lines to have more knowledgeable personnel and increase the collaboration among other branches. Successful digitalization can also be achieved through mutual effort and collaboration among the partners. Special attention must be given to the voice of both suppliers and customers as well as the employees. This is vital in the shipping industry, which has been traditional for many years but is now transforming into a digital era.

The study is subject to several limitations. For instance, the results of the study can only be generalized after being tested in other regions. This is important especially considering the potential differences within the IT structure and culture between the countries. Other ecosystem members of container shipping such as terminals and shippers are also not involved in this paper. The results of this study might be tested with other ecosystem members considering their perspective in digitalization as well. While doing this, the maritime logistics concept can be utilized as the main framework to involve the relevant stakeholders. In this case, instead of RBV theory, the network theory and stakeholder theory are ideal in underpinning the theoretical background. Moreover, the digitalization in the shipping industry can be studied through the perspectives of Industry 4.0 and COVID-19. Despite significant benefits of digitalization applications during COVID-19 disruption, the literature has not investigated how and to what extent the digitalization can enhance resilience in the maritime logistics context. Future studies may address these issues while investigating the digitalization in the shipping industry.

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Model Proposal for Future Estimates in Maritime Industry: The Case of Container Handling in Turkish Ports

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Abstract

Future planning is difficult in several industries, including the maritime sector, especially with the current pandemic because of numerous active dynamic factors. Thus, this study aimed to determine the freight demand estimates based on the Twenty-foot Equivalent Unit-based monthly number of containers handled in Turkish ports by comparing the prediction accuracy and reliability of artificial neural network (ANN) models with various algorithms using the "exponential smoothing" and "Box-Jenkins" time series methods. The monthly container volume handled in Turkish ports between January 2005 and December 2018 was used, and augmented Dickey-Fuller tests were conducted with the EViews 5 software. Results from several tests revealed that the 12-time delay ANN model, which was developed with the original series, provided the highest accuracy. In this study, the demand forecasts for the container volume that would be handled in Turkish ports were conducted for the year 2022 with the developed model, and a methodological approach was presented for the forecast models in different maritime industry fields.

Keywords

Container, Maritime commerce, Artificial neural networks, Time series, Turkey

1. Introduction

Container shipping is one of the most important international shipping industry structures. Several products are transported with container shipping and annual reports demonstrate its growth every year in Turkey and globally [1]. The vessel capacity in container shipping routes is estimated to be approximately 253 million tons per vessel and will increase by 1-2% with new vessel orders [1,2]. The container movements around the world were reported to be about 750 million Twenty-foot Equivalent Unit (TEU) as of 2019 [1,3]. Furthermore, the global container demand increased by 3.2% between 2012 and 2018, 2.5% between 2012 and 2016, and 4.7% between 2016 and 2019, exhibiting a positive differentiation compared to other shipping modes [1,3-5]. Having a similar development with the global market, the Turkish foreign trade comprised 86% of the Turkish market, in which 387 million tons were shipped by sea routes in 2018. In these periods, the preference for container modes in the Turkish maritime freight and Turkish exports was about 20% and 33%, respectively [6]. This high global container shipping volume could be attributed to important factors including the suitability of this mode for intermodal transport and its availability for port-to-port, door-to-door, and between different delivery points [7-10].

With the expansion of supply chains, the role of ports has gradually increased and port operations have become more complex. The fact that the ports are facing strong competition requires the improvement of services provided by port authorities and operators. The survival of these businesses in a globally competitive environment most importantly relies on the more effective utilization of business structures, understandings, and scientific-based forecasting models. Therefore, rapid environmental changes should be followed continuously and carefully, and port management strategies should be developed according

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to these changes. People tasked with making decisions in maritime transports have to make the best business choices and plans as quickly as possible. More importantly, these decisions need to be accurate to avoid heavy losses that are very difficult to reverse. The process of predicting the future of ports is also complex and several criteria must be considered. Therefore, before making investments and future plans, decision makers should be able to create these complex relationship networks with scientific estimation and modeling techniques to quickly obtain results and accurately predict the effects of the decisions made on the results [10-13].

Container shipping is reported to be an ideal, economical, and safe transportation mode for overseas, high-tonnage, and various types of cargo [14,15]. Furthermore, it is considered as an important investment tool for national economies through strategic partnerships in container trades, improvement of container shipping productivity, advantages of the economies of scale, and distribution of financial costs and risks [16-19]. However, there exists a race to increase the market share among national competitors. Thus, nations could make a difference in the container lines to enter in new markets, provide intermodal services, and develop value-added products and services. Countries compete for the highest share in container shipping to acquire a stronger strategic position in the foreign exchange and freight revenues. Initially, two countries compete in a region to increase their share in container shipping, which is the most active mode of maritime transportation. The ports of the regional competitors try to improve their positions in this race and achieve a more advantageous position. In Turkey, three main routes exist for container transportation: (1) the transatlantic (between Europe and Americas), (2) the transpacific (between Asia and Americas), and (3) the Eurasian line (between Europe and the Far East) [20]. Turkey is located on the Eurasian maritime line between the Far East and Europe and in the northern Transport Corridor Europe-Caucasus-Asia project because of its low miss distance [21], which is a very advantageous position. The development of a higher freight demand and increasing its contribution to the economies of scale would be possible with careful analysis of the dynamic processes [22]. Because of the fragile structure of the maritime industry where global risks always prevail, focusing on multidisciplinary studies and future estimates and models would reduce these risks. The global pandemic is an appropriate example of events that could adversely affect the delicate dynamics of the maritime trade. This study aims to develop realistic forecast models with a different approach based on the container volume handled in Turkish ports (based on total TEU) to provide an exemplary model for container shipping, which is an essential building block in the maritime industry, and to provide realistic estimates for the future. This study also aims to contribute to the management of Turkish ports in possible future dynamic processes for 2022. The availability of scientific data will increase the competitiveness of the Turkish maritime industry in the global container shipping market. The findings of the study will reveal the current status of the industry in this process. Similar to the current study, scientific estimates aim to overcome future risks based on national strategic plans and future visions. Thus, the present study aims to determine the freight demand estimates based on the TEU-based monthly number of containers handled in Turkish ports by comparing the prediction accuracy and reliability of artificial neural network (ANN) models with various algorithms using the “exponential smoothing” and “Box-Jenkins” time series methods. Consequently, certain recommendations are presented.

2. Methodology

The present study aims to construct a hybrid prediction model with ANNs, exponential smoothing, and Box-Jenkins methods. The methodological methods are presented below.

2.1. Artificial Neural Networks

In literature, ANNs are described as computing systems that could provide solutions for statistical, mathematical, decision-making, risk management, and philosophical problems to accomplish a task or a goal through a combination of numerous neurons based on certain rules [23,24]. In general, ANNs produce new information based on previously learned or coded information and data by imitating the human nervous system [25,26]. ANNs are frequently employed in software in several fields such as prediction models, robotic applications, signal processing, energy efficiency, and nonlinear control [27-30].

There are three inputs in an ANN algorithm, i.e., the neuron (called the artificial neural cell), connections, and learning diagram. The artificial neural cell is the main element of the ANN algorithm [27]. Neurons in the ANN algorithm receive one or more inputs based on the inputs that affect the problem and provide an expected number of outputs based on what the problem requires. The ANN algorithm is developed by connecting the artificial nerve cells. In ANN algorithms, a cluster of neurons in the same direction forms the layers [23,29]. Figure 1 shows an ANN algorithm model.

2.2. Exponential Smoothing Method

In contrast to the simple moving averages (MAs) method where the historical data have equal weights, the exponential smoothing method can be described as a collection of methods similar to the simple MAs method. However, the simple MAs method assigns different weights to the historical data compared with the exponential smoothing method [31,32]. This means that the weights assigned as exponential terms decrease exponentially as the existing inputs get older. In the exponential smoothing method, the historical data, which are generally used for prediction, are assigned higher weights when they are relatively recent and the assigned weight decreases as the data get older [33,34].

In this method, determining the smoothing coefficients that would provide the lowest mean squared error for the algorithm is a very important step. In general, the method includes a combination of different techniques based on the characteristics [32,33,35]. These methods include the single (simple) exponential smoothing method, Brown's single parameter linear exponential smoothing method, Holt's double parameter linear exponential smoothing method, and Winters' seasonal exponential smoothing method. In the literature, the Winters' seasonal exponential smoothing method is preferred in the prediction of the inputs that are under the influence of trends and seasonal variations. This method includes four equations to smooth the three inputs for each algorithm, namely the data dependent on trends, random, and seasonal variations [36,37]. These 4 equations are given below:

$$K_p = Q\frac{M_p}{R_{p-r}} + (1-Q)(K_{p-1} + b_{p-1}) \quad (1)$$

$$b_p = ß\left(K_p - K_{p-1}\right) + (1-ß)b_{p-1} \quad (2)$$

$$R_p = y\frac{L_p}{K_p} + (1-y)R_{p-r} \quad (3)$$

$$R_{p+a} = (K_p + b_p a)R_{p-r+a} \quad (4)$$

Where "R" is the number of seasons in a year, "K_p" is the general level of the current series in period "p", "b_p" is the trend input, "R_p" is the seasonal component, and "R_{p+a}" is the forecast for future period "a". "Q", "ß", and "y" are the Winters' method's smoothing constants; "Q" is the average smoothing constant in the model, "ß" is the trend smoothing constant, and "y" is the seasonal smoothing constant.

2.3. Box-Jenkins Method

The Box-Jenkins algorithm is generally known as a hybrid of the "autoregressive (AR)" and "MA" methods, and it is widely applied in various fields. The main objective of the Box-Jenkins technique is to develop a linear model with the most ideal and lowest number of data in the time series [38]. One of the most important advantages of this method is its ability to provide an ideal solution without focusing on whether the series is static or whether there are seasonal effects [33,39]. These models, which constitute the main structure of the Box-Jenkins method, include the non-seasonal and seasonal models. Thus, Box-Jenkins technique is also called AR integrated MA method (ARIMA) in the literature [37]. The non-seasonal Box-Jenkins models are generally described as ARIMA (p,d,q) $(P,D,Q)_s$, where "P" refers to the degree of the seasonal AR (SAR) model, "D" is the number of seasonal variance operations, "Q" is the degree of the seasonal MA (SMA) model, and "S" is the seasonal period. In the seasonal ARIMA algorithm in (P,D,Q) degrees, the backward shift operator is expressed as given in Equation 5 is below.

$$\theta_p(A^L)\Delta_L^M X_c = \sigma_\exists(A^L) \in_c , \quad (5)$$

where "Δ_L" denotes the seasonal difference operator and "L" denotes the seasonal periods, which is given a value of "12" for a monthly data. "Δ^M" denotes that the seasonal difference was taken "M" times. After the transformations are conducted for all the operators in the system, the stationarity of the series is ensured and the non-stationary series is accepted as a stationary series after the "Δ_L^M" operation. "θ_p" and "$\sigma_\exists$" refers to the SAR and SMA, respectively.

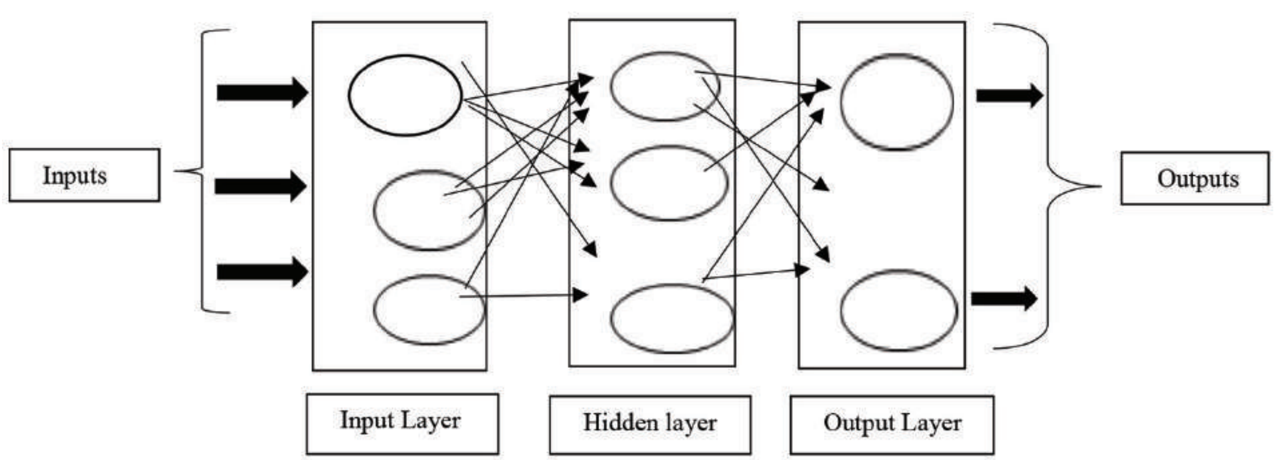

Figure 1. *An artificial neural network algorithm model*

In this technique, the current data values are based on the combination of the weighted sum of the previous data and random shocks. Thus, in the determination of the model, the stationarity of the series and the presence of the seasonal effects are the differentiating criteria. Therefore, the features of the time series used in the first stage should be determined and an ideal model approach should be adopted. In this method, a four-step iterative approach is preferred to determine the ideal approach among all model combinations. These four steps include the determination, parameter estimation, fitness tests, and prospective estimation stages. When the approach determined in the process is not at a desired level, the process is repeated until another model, which is developed to improve the original model, provides a satisfactory result [33,37,39].

3. Case Study

This study aimed to develop the freight demand estimates using the monthly container volume handled in Turkish ports (based on TEU) with the most reliable model determined through the comparison of the prediction accuracy and reliability of ANN models with different algorithms based on the time series models of exponential smoothing and Box-Jenkins techniques. This study used the monthly container volume handled in Turkish ports between January 2005 and December 2018.

3.1. Study Data

The total container volume handled in Turkish ports between January 2005 and December 2018 was analyzed. In the literature, the total handling volume is considered among the most important productivity data for the ports. Moreover, the demand in container ports is measured with the total container volume handled in the ports in the literature [15,18,38,40]. The data for the container volume handled in Turkish ports were obtained from statistics reports published by the Ministry of Transportation and Infrastructure. The total monthly data were analyzed for the specified period. A monthly data was selected to conduct more detailed analyses based on the seasonal and trend variables.

3.2. The Research Method

In the first phase of the study, the main factors that affected the series were determined with the analysis of the properties of the time series data for determining the adequate techniques for the collected data. In the next phase, the January 2005-December 2018 data were used to forecast the monthly container volumes that would be handled in the Turkish ports in 2021 and 2022 (January-December) using the models that are suitable for the data along with the ANN models with exponential smoothing and Box-Jenkins methods. The forecasts were compared with the actual container handling figures to determine the most realistic and ideal model. The prediction accuracy of the applied algorithms was tested with the "mean absolute percentage error (MAPE)" statistics. The fact that the MAPE statistics expresses prediction errors as a percentage is considered as a superiority when compared to other criteria because of its standalone meaning in the literature [26,28,39,41-45]. In previous studies, the accuracy of the prediction models is classified according to their MAPE values: (1) highly accurate, MAPE <10%; (2) accurate, MAPE is between 10% and 20%; (3) acceptable, MAPE is between 20% and 50%; and (4) inaccurate, MAPE >50% [26,34,39,40,43,44]. Equation 6 represents the MAPE algorithm.

$$MAPE = \frac{\sum_{k=1}^{r} \frac{|b_k|}{z_k}}{r} \; 100(\%). \qquad (6)$$

When $b_k = z_k - \hat{z}_k$ for $z_k = k$" period, $\hat{z}_k = k$ is the calculated estimate for the period, "r" is the number of estimated periods, and $b_k = k$ is the prediction error in the period.

3.2.1. Determination of Time Series Components

The time series was analyzed in the study. The analysis of the data for 168 months in Figure 2 (January 2005-December 2018) revealed an increasing trend and that the data were affected by the seasonal fluctuations. The fluctuation started increasing in March in successive years and reached the maximum in August and September. The lowest fluctuations were observed in January. The source of fluctuations is assumed to be because of the seasonal trade effects.

3.3. Application of the Methods

In this section, the forecasts conducted with exponential smoothing, Box-Jenkins techniques, and ANNs are addressed. Due to the increasing trend of the study data and the impact of seasonal fluctuations, the adequate time series methods, i.e., the "seasonal exponential smoothing" and "seasonal Box-Jenkins" methods were used.

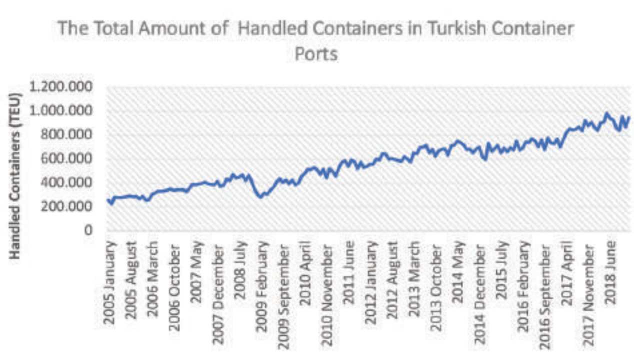

***Figure 2.** Analysis of the data for January 2005-December 2018*

TEU: Twenty-foot Equivalent Unit

3.3.1. Seasonal Exponential Smoothing (Winter's) Method

The technique was applied with SPSS 22.0 statistics software. Seasonal index values obtained with seasonal deconstruction were employed as seasonal factors. The smoothing constant "Q", trend smoothing constant "ß", and seasonal smoothing constant "γ" parameters in Equations 1, 2, 3, and 4 were determined to minimize the square sum of errors in the model. Based on the calculations, Q=0,8000000, ß=0,000000, and γ=0,000000 were used as the smoothing coefficients in the model. The initial model values were calculated with the software and the following were determined: K_r=51764,15324 (initial level) and b_r=231,025421 (initial trend).

3.3.2. Seasonal Box-Jenkins Method

The initial application of the Box-Jenkins technique determined that the seasonal component in the data was not constant with time, and the natural logarithm of the data was taken to include seasonal variations in the original data. Stationarity analyses were conducted with the augmented Dickey-Fuller (ADF) tests. The results revealed that the series was stationary after the first-order seasonal difference was taken (D=1, S=12). Autocorrelation and partial autocorrelation functions of the data were analyzed, and the seasonal and non-seasonal AR and MA degrees were obtained. The adequate range for AR, MA, seasonal AR, and seasonal MA was determined to be p=1, q=0, P=0, and Q=1 for seasonal MA. These values revealed that the ideal algorithm for the total container volume handled in the Turkish ports series (based on TEU) that was dependent on a logarithmic transformation was ARIMA (1,0,0) $(0,1,1)_{12}$, the "multiplicative-seasonal ARIMA Model." The final parameter estimates for the developed model are presented in Table 1. All t-values associated with the parameter estimates of the algorithm presented in the table were statistically significant at "0.00" significance level (furthermore, seasonal parameter estimates provided |t|>1.25).

After the statistical analysis conducted on the data estimates of the model, the "Ljung-Box (Q*)" statistics method was used to test whether the residuals of the model were random (white noise) and whether there was autocorrelation between them. The "Q*" statistics calculated based on the 14th, 26th, and 38th delays for the residual series of the model demonstrated that there was no significant autocorrelation between the residuals; the residual series had a random function, and the algorithm was suitable. Box-Jenkins models were applied with autocorrelation and partial autocorrelation functions, and ADF tests were calculated with EViews 5 software, which is a statistical package software for the Windows operating system and frequently used especially for econometric analysis. It has a unique programming language that combines the spreadsheet and relational database infrastructure with the features of traditional statistical software. Although EViews can also be used for general statistical analysis, it is preferred especially in regression analysis and econometric analysis. Panel data, time series, and cross-section analysis can be done with EViews.

3.3.3. Artificial Neural Networks

In the stage where the study data was modeled with ANNs, the prediction performances of various ANN algorithms developed with three datasets were analyzed. Out of the 198 monthly parameters, 180 were categorized as training data for the 2003-2018 period and 18 were categorized as test data for the January 2019-June 2020 period. Various time lag data "$(z_{k-1}, z_{k-3}, z_{k-12} \ldots z_{k-u})$" were employed in the input layer, and the data without lag "(z_k)" were employed in the output layer. The calculations were conducted with the neural networks' module (Neural Network Toolbox) of the MATLAB 7.0 software. The study data were first normalized for the [0:1] range and then employed in the software. The data were normalized with Equation 7 given below.

Table 1. *ARIMA (1,0,0) $(0,1,1,)_{12}$ model parameter estimates*

Variable	Estimate	Standard error	t-statistics	p-value
AR (1)	0.72165303	0.05021743	16.503121	0.00000000
SMA (1)	0.50349610	0.04976017	9.341063	0.00000000
Constant	0.11830190	0.03011086	4.010716	0.00000601
Number of observations	267			
Number of observations after noticing	255			
Akaike information criteria	91.631202			
Sum of error squares	18.010030			
Standard error	0.26013218			
Converting and difference	The seasonal first difference of the series whose Napierian logarithm is taken (s=12)			
AR: Autoregressive, SMA: Seasonal moving average				

$$Y_n = \frac{Y_0 - Y_{min}}{Y_{max} - Y_{min}} \quad (7)$$

where "Y_0" is the original data, "Y_n" is the normalized data, "Y_{min}" is the smallest number in the dataset, and "Y_{max}" is the greatest number in the dataset.

For the analyzed datasets, models with different hidden layers (between 1-5) and different neurons (between 1-5) were constructed in the study. The training was conducted with experiments with various iterations (5,000-50,000). All models were then tested with the data reserved for testing. The predictive accuracy of ANN models with different algorithms was measured by comparing the predicted figures with the actual figures.

Several tests were conducted, and the predictive accuracy and reliability of the models were observed to decrease with increasing number of neurons in the hidden layer and the number of neurons in the hidden layer of the tested models. The twelve-lag model gave the most accurate results among the different ANN models. Because the systematic pattern (seasonal cycle) in the datasets repeated every twelve months, the twelve-lag models yielded better results compared to the one- or three-lag models. There was an input, a hidden, and an output layer in the model with six neurons, three neurons, and one neuron, respectively. Figure 3 represents the related ANN model.

A feedforward-backpropagation network algorithm was used in the constructed model, the logarithmic sigmoid algorithm was selected as the activation function and the Levenberg-Marquardt algorithm was selected as the training function, and 30,000 epochs (epoch: single feedforward in an ANN) were conducted in the model training.

4. Findings

To determine the ideal model and algorithm for the prediction of the TEU-based total container volume handled in Turkish ports in the future, the accuracy measurements

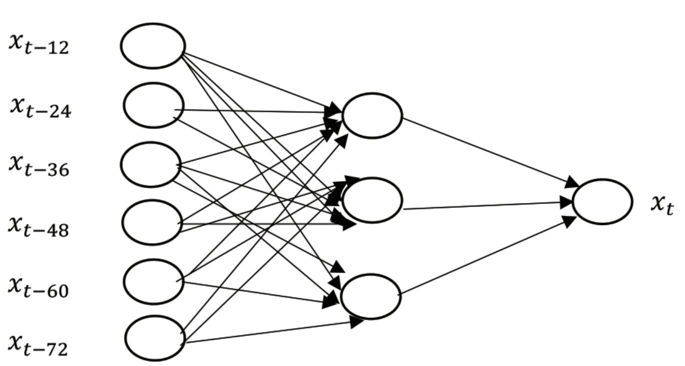

***Figure 3.** The ANN design*

ANN: Artificial neural networks

conducted on the predicted figures with the analyzed methods and actual figures were analyzed. Table 2 presents the related data.

ANNs showed highest prediction accuracy and provided the closest results to the actual figures. ANNs could learn nonlinear correlations between the parameters and generalize the findings, thus answering questions that were never encountered before within an acceptable margin of error. Due to these features, the ANN method was preferred in forecasts.

As discussed in Section 3.2, the models with a MAPE value <10% were classified as "very good", those between 10% and 20% were classified as "good", those between 20% and 50% were classified as "acceptable", and those >50% were classified as "inaccurate" in the literature. The figures presented in Table 2 show that in the predictions obtained with the ANNs and multiplicative-seasonal Box-Jenkins techniques, the "MAPE" figures were <10%, whereas the seasonal exponential smoothing (Winters) method had a MAPE value of 12.97%. This suggested that all three techniques provided accurate predictions. Among these methods, the Winters' seasonal exponential smoothing method was the most preferred because it could be employed for the data that exhibit trends and parameters with seasonal fluctuations. Furthermore, the Box-Jenkins model techniques are frequently employed in the literature because they require no additional data for prediction and have proven to yield short and medium-term prediction accuracy in previous studies. In addition, their ability to determine the ideal model among various models and test the suitability of the determined model for the parameters in every process emphasizes the significance of these methods. However, the 12-lag ANN techniques were observed to exhibit low deviation compared to the seasonal exponential smoothing and Box-Jenkins method findings. The comparison of the prediction accuracy of the analyzed techniques demonstrated that the ANN model with the [5-3-1] order led to the most reliable result. Thus, this technique was preferred for the prediction of the total container volume handled in Turkish ports for 2022 based on TEU. Table 3 presents the data analysis findings for this technique.

***Table 2.** Prediction accuracy of analyzed techniques*

Techniques	MAPE (%)
Artificial neural networks	6.03
Box-Jenkins ARIMA (1,0,0) $(0,1,1)_{12}$	8.53
Seasonal exponential smoothing (winters)	12.97
MAPE: Mean absolute percentage error, ARIMA: Autoregressive integrated moving average method	

5. Conclusion and Recommendations

Proactive predictions in the maritime industry based on scientific approaches would facilitate future economic policies and national strategies and allow more realistic forecasts. Demand is the main factor for investments in the maritime industry, and the investments are a function of the quantitative and qualitative attributes of demand. In the maritime industry, the investments require a very high budget, and the success of policies and projects depends on the forecast of future demands and market structures, thus matching the supply resources and demands. Realistic and reliable demand forecasts are a prerequisite for efficient organization of all operational activities, primarily the ship routes, port infrastructures, maritime logistics network, and national maritime policies. Thus, determining adequate techniques for the properties of the analyzed parameters that reveal the most accurate and reliable predictions for future demand is important. The present study aimed to determine the model with the highest reliability in predicting the total monthly and annual container volume handled in Turkish ports based on TEU by comparing the prediction accuracy of ANN models that included different algorithms with time series methods of exponential smoothing and Box-Jenkins. Analysis of the findings demonstrated that the ANNs method exhibited the highest prediction accuracy and provided the closest results to the actual figures. ANNs could learn nonlinear correlations between the parameters and generalize the findings, thus answering questions that were never encountered before within an acceptable margin of error. Because of these features, the ANN method was preferred in forecasts. Based on both the present and previous results, ANN models without problems, such as overtraining and incorrect algorithm development, provided better results compared to the models constructed with other methods. In the literature, ANN algorithms provide highly effective results in nonlinear and dynamic models. On the other hand, the model does not allow the interpretation of the problems in contrast with the statistical methods. Moreover, the model remains a closed box for the results obtained with ANNs. The total monthly and annual container volume handled in Turkish ports for 2022 was predicted with the ANNs' technique whose reliability was tested in the present study. A similar study was also conducted by Gökkuş et al. [45] that discussed the ports of Izmir, Mersin, and Istanbul for 2023 using the past records of the gross domestic product, exports, and population of Turkey as indicators of socioeconomic and demographic status. For the testing period, their study reported that the LSSVM, ANN-ABC, and ANN-LM models performed better than the MNR-GA model considering overall fitting and prediction performances of the extreme values in the testing data. In contrast to the study of Gökkuş et al. [45], several tests conducted in our study revealed that the 12-time delay ANN model, which was developed with the original series, provided the highest accuracy. The fact that the dynamic factors are always active in the maritime industry, especially during the current pandemic, and the inability to predict the future increases the value of related studies such as the present research. Now, with the proposed model, reliable and flexible solutions can be provided to decision makers. The adaptation process of this method to the problem and the obtained results show that the method is simple, intelligible, and useful enough for the maritime sector. As a solution, quantitative method approaches are considered to be very effective in solving complex problems in the maritime sector, this helps in obtaining a more concrete cluster of alternatives and reaching more realistic solutions.

Table 3. *Predictions for monthly container handling in Turkish ports in 2022*

Months (year 2022)	Total number of containers to be handled (TEU)
January	897246
February	887524
March	975256
April	1098214
May	1010245
June	1089624
July	1174526
August	1078562
September	970952
October	987452
November	1005877
December	921485
TOTAL	12,096.963

TEU: Twenty-foot equivalent unit

The main limitation of our study is related to the characteristic of the examined container port in Turkey. Turkish container ports have the characteristic of being a transit port because they are located on the main shipping routes, which necessitates the consideration of the transportation consisting transit loads. Hence, the data set of the study is limited to Turkish container ports.

In future studies, ANN models with different algorithms could be employed to predict the container volume, general cargo load, liquid bulk cargo, number of passengers, etc. Furthermore, national, regional, or port vessel arrivals; the average length of stay in the ports; the average duration of handling operations in the ports; could be predicted in future studies. The forecast performances of hybrid models that combine ANNs and time series prediction methods could also be determined. Thus, considering the limited number of studies conducted with ANNs and hybrid approaches in maritime commerce, the above-recommended studies would significantly contribute to future planning studies by maritime industry personnel and decision makers. Because no similar study is available in the maritime literature, the present study would guide researchers who plan to conduct future studies in the field.

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Analysis of Strategies to Reduce Air Pollution from Vessels: A Case for the Strait of Istanbul

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Abstract

Air pollution that stems from vessels has become a critical problem especially for people living in cities with heavy maritime traffic. Istanbul City is an important metropolis of the region and the world. This study proposed strategies to reduce air pollution in the Strait of Istanbul by extending the International Maritime Organization and European Union strategies' scope. The strategies' priority levels were analyzed employing the fuzzy analytical hierarchy process method by asking opinions from experts who live in the Strait of Istanbul as a marine pilot or vessel traffic operator with at least 10 years of existing work experience. The analysis results determined which types of ship that passes the strait are more sensitive to the above mentioned strategies using the fuzzy technique for order preference by similarity to ideal solution method. Accordingly, the strategies under the "Declaration of the Strait of Istanbul and the Marmara Sea as a Sulfur Emission Control Area" and "prohibition of the use of heavy fuel on ships" have been the highest priority strategies in reducing air pollution in the strait. The direct passing ships achieved the highest sensitivity level to the strategies held in this study according to the selected experts.

Keywords

Air pollution, Strait of Istanbul, Strategies, Fuzzy logic

1. Introduction

The industrial revolution, which was achieved using carbon dioxide (CO_2) producer fossil fuels as energy sources, has continuously increased production capacities with the products transported worldwide with the effect of globalization. The maritime transportation structure that is suitable for providing economies of scale ensures the transport of 80%-90% [1] of these products between ports. The effects of maritime transport on CO_2 emissions were brought on the agenda in the 1980s. It is estimated that maritime accounts for approximately 43% of the total energy used in world transportation [2]. According to the reports published by the International Maritime Organization (IMO), CO_2 emissions from vessels accounted for 2.6% of the total annual world CO_2 emissions, whereas sulfur and nitrogen emissions from vessels accounted for 15% and 13%, respectively. Moreover, 70% of the vessel emissions were reported to be generated in offshore areas closer than 400 km from land. For example, the emissions from shipping activities in Shanghai accounted for approximately 12% of the city's emissions [3]. Alternatively, according to the report, "Time for International Action on CO_2 Emissions from Shipping," published by the European Union (EU) [4], CO_2 emissions from maritime transportation can be doubled if no precautions are taken.

The efforts for preventing air pollution from shipping were first brought on the agenda by the Marine Environment Protection Committee (MEPC), an IMO subsidiary in 1988. The first step was implemented in May 2005 with the International Convention For The Prevention Of Pollution From Ships (MARPOL) Annex VI that imposed restrictions regarding the ship's emissions. These restrictions have increasingly become more compelling and stricter over the years. The last regulation "IMO 2020" requires the

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ship owners to either the switch type of fuel with a cleaner one (0.5% SO_x, very low sulfur fuel oil), or equip on board pollutant abatement (scrubber) systems [5]. To better illustrate the urgency of this regulation, a report in the IMO's 70th session of the Marine Environment Protection Committee forecasts a 77% increase in sulfur emissions and 570,000 early deaths if these regulations, which came into force as of January 01, 2020, are postponed for five years [6]. Although these regulations are an important step toward reducing air pollution, difficulties in implementation, detection, and follow-up of this regulations bring some concerns. To overcome these concerns, supporting incentive activities, taking additional precautions, and carrying out regional-specific work are recommended.

Istanbul City has grown 6 times in population over the last 50 years and the city is an important metropolis of the region and the world. As in many megacities, air pollution is a critical problem for Istanbul City as well. According to the report published by the Republic of Turkey Ministry of Environment and Urban Development in 2017, gas emissions in Istanbul City are above the desired limits. The main sources of air pollution in Istanbul City are the vehicles and industrial emissions [7]. In addition to the heavy urban land traffic, dense maritime activities owing to the location of the city connecting the continents contribute significantly to the production of these emissions. Maritime transport activities in Istanbul City can be classified as the following: (1) vessels stopped over in ports, (2) vessels passing without stopover, and (3) local maritime traffic. Istanbul City has 16 port facilities that are frequently visited by ships [8]. According to the Maritime Trade Statistics Report published by the Republic of Turkey Ministry of Transportation and Infrastructure [9], 6472 ships visited these ports in 2018. In addition to the international maritime vessel traffic, ferry services in this region carried 114,235,943 passengers in 2018. Moreover, the Strait of Istanbul, which is 17 nautical miles long and has an average of 55,000 ships passing every year, is a unique waterway in the region. Approximately 150 ships pass through the Strait of Istanbul every day, of which 27-28 ships carry dangerous goods. Furthermore, the Strait of Istanbul has 2500 local maritime traffic that transports approximately 2,000,000 people. Besides the physical, oceanographic, and meteorological elements that restrict the safety sailing in the strait, the Strait of Istanbul is four times denser than the Panama Canal (in terms of the number of ships passing) and has three times heavier traffic than Suez Canal [10]. The negative contribution to air pollution of the ships passing through the Strait of Istanbul accounts for approximately 10% of the total air pollution in this geography [11]. The annual estimation of ship emissions in the strait comprises 7295.5 tons of NO_x and 6062.5 tons of SO_2 [12].

Studies in the literature related to the emissions produced by the ships in the Strait of Istanbul have focused on detecting the amount of emissions and in developing strategies to reduce these emissions. Im et al. [13] determined the terrestrial and marine emissions in Istanbul City. Meanwhile, Kılıç [14] tried making annual emission estimates of merchant ships in the Marmara Sea, and Bayırhan et al. [11] measured the exhaust emissions of ships passing through the strait based on actual ship movements and ship machinery information. Alternatively, Dogrul et al. [12] evaluated the effects of gas emissions on the Strait of Istanbul according to various weather scenarios. To prevent marine-induced emissions in Istanbul City, Öztürk and Küçükgül [15] evaluated certain precautions to be taken against air pollution in the port areas and stated that the activity should be organized according to the principles of environmental management planning to minimize the environmental impacts of the ports. Further, the authors suggested that the environmental management activities should be carried out with a holistic approach throughout the ports. Han [16] proposed technical, operational, and market-based strategies to reduce air pollution from marine vessels and emphasized the importance of using these strategies together. Peksen and Alkan [17] estimated the gas emissions from the sea vehicles by comparing the conditions of the Marmara region, which is declared as an emission control area. The authors revealed the benefits of being an emission control area of the region to its air quality. Rață et al. [18] determined the air pollution from vessels navigating the Black Sea and the area that will most likely be affected. They proposed to use a higher quality of fuel to reduce sulfur emissions from marine vessels in coastal areas, to equip scrubbers to ships, and to restrict the ships' speeds within the limits of 200 nautical miles. Lastly, Tatar and Özer [19] revealed the carbon emissions from global shipping and suggested strategies such as improvement/development on the equipment, transition to renewable energy, and using ultralow sulfur content fuel to reduce carbon emissions.

This study developed strategies to reduce the emissions caused by marine vessels in Istanbul City, and the vessel types diversifying the service they offered were evaluated by considering their sensitivity levels to these strategies. In the following part of the study, the methods employed in the analyses were introduced and the application steps were explained. After, the problem was identified, the experts who were consulted were introduced, and the findings of the analyses were presented. In the conclusion, the results were interpreted and suggestions were made regarding the implementation of the prominent strategies.

2. Methodology

The analytic hierarchy process (AHP) method is a multicriteria decision-making method that is widely used becuase it is easy to understand and use in both quantitative and qualitative data analyses. This method is based on subgrouping, pairwise comparisons, priority vector production, and syntheses [20]. The most important advantage of using this model is its specialty to transform the qualitative expressions of the experts to analyzable quantitative variables. However, the conventional AHP can fail to fully reflect human thoughts and is often criticized for this reason. Thus, the fuzzy AHP method has been developed to accommodate one's self to the indecisive nature of linguistic assessments [21] and to address the deficiencies of the traditional AHP method in reflecting human thoughts [22-24].

Linguistic variables are expressed in five basic terms whose values are in a natural or artificial language. These terms are the fuzzy five-level scale values: (1) absolutely important, (2) very strongly important, (3) essentially important, (4) weakly important, and (5) equally important [25]. Table 1 shows the linguistic equivalents of the fuzzy numbers. In this study, the preference levels of the preventive strategies against air pollution from vessels around the Strait of Istanbul based upon pairwise comparisons were evaluated via nine basic linguistic terms: (1) absolutely strong, (2) very strong, (3) fairly strong, (4) slightly strong, (5) equal, (6) slightly weak, (7) fairly weak, (8) very weak, and (9) absolutely weak. Table 2 shows the results derived from the preliminary analysis of the representation of each linguistic variable as a triangular fuzzy number (TFN) in the 0-9 scale range.

Table 1. *Triangular fuzzy conversion scale [21]*

Linguistic scale	TFNs/reciprocal TFNs
AS-absolutely strong	(3.50, 4.00, 4.50)
VS-very strong	(2.50, 3.00, 3.50)
FS-fairly strong	(1.50, 2.00, 2.50)
SS-slightly strong	(0.50, 1.00, 1.50)
E-equal	(1.00, 1.00, 1.00)
SW-slightly weak	(0.67, 1.00, 2.00)
FW-fairly weak	(0.40, 0.50, 0.67)
VW-very weak	(0.29, 0.33, 0.40)
AW-absolutely weak	(0.22, 0.25, 0.29)
TFN: Triangular fuzzy number	

Table 2. *Fuzzy evaluation scores for the alternatives [26]*

Linguistic terms	Fuzzy score
Absolutely poor-AP	(0.00, 1.00, 2.00)
Very poor-VP	(1.00, 2.00, 3.00)
Poor-P	(2.00, 3.00, 4.00)
Medium poor-MP	(3.00, 4.00, 5.00)
Fair-F	(4.00, 5.00, 6.00)
Medium good-MG	(5.00, 6.00, 7.00)
Good-G	(6.00, 7.00, 8.00)
Very good-VG	(7.00, 8.00, 9.00)
Absolutely good-AG	(8.00. 9.00, 9.00)

If M_1 and M_2 are considered TFNs, addition, multiplication, and inverse operations can be performed on the TFNs following the 3 equations below:

Addition: $M_1 \oplus M_2 = (1_1+1_2, m_1+m_2, u_1+u_2)$ (1)

Multiplication: $M_1 \otimes M_2 = (1_1.1_2, m_1.m_2, u_1.u_2)$ (2)

Inverse: $M_1^{-1} = (1_1, m_1, u_1)^{-1}.(1/u_1, 1/m_1, 1/1_1)$ (3)

This study aims to analyze the efficiency level of the strategies that involve precautions against the air pollution generated from the vessels around the Strait of Istanbul on the selected vessel types using the fuzzy technique for order preference by similarity to ideal solution (TOPSIS) method. According to the TOPSIS concept, the most suitable alternative should have either the shortest distance from the positive ideal solution (PIS) or the farthest distance from the negative ideal solution (NIS) [27]. In this study, an extended fuzzy TOPSIS method similar to that applied by Hwang and Yoon [28] and Ertuğrul and Karakaşoğlu [29] was used. The application steps of the fuzzy AHP-TOPSIS hybrid method to be implemented in the study are as follows:

Step 1: A pairwise comparison matrix that comprises comparisons of each criterion in the hierarchy system was constituted. Formula 4 is below.

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \dots & \tilde{a}_{2n} \\ \dots & \dots & 1 & \dots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & 1 \end{bmatrix} \quad (4)$$

Accordingly, $\tilde{a}_{ij}$ is a TFN and when $\tilde{a}_{ij} = l_{ij}, m_{ij}, u_{ij}$, it is expressed as $\tilde{a}_{ij} = l_{ji}, m_{ji}, u_{ji}$.

Step 2: The elements of the pairwise comparison matrices were calculated via the formula 5 below by using the geometric mean method suggested by Buckley [30]:

$$\tilde{a}_{ij} = (\hat{a}_{ij}^{1} \otimes \hat{a}_{ij}^{2} \otimes \ \dots \ \otimes \hat{a}_{ij}^{n})^{1/n} \tag{5}$$

Step 3: The r_i value that is necessary for calculating the criteria weights was obtained using the following formula 6:

$$\hat{r}_i = (\hat{a}_{i1}^{1} \otimes \hat{a}_{i2}^{2} \otimes \dots \otimes \hat{a}_{in}^{n})^{1/n} \tag{6}$$

Step 4: The formula 7 below was applied to calculate the weights of each criterion.

$$\widehat{w}_i = \hat{r}_i \otimes (\hat{r}_1 \oplus \hat{r}_2 \oplus \dots \oplus \hat{r}_n)^{-1} \tag{7}$$

Step 5: The values of the fuzzy PIS, FPIS (A^+), and the fuzzy NIS, FNIS (A^-), were determined using the following formulas 8 and 9:

$$A^+ = (\tilde{v}_{\underline{1}}^{+}, \tilde{v}_{\underline{2}}^{+}, \dots, \tilde{v}_{\underline{n}}^{+}) \tag{8}$$

$$A^- = (\tilde{v}_1, \tilde{v}_2, \dots, \tilde{v}_n) \tag{9}$$

where $v_j^+ = \max\{v_{ij1}^+\}$ and $vj^- = \min\{v_{ij1}^+\}$, i=1, 2, ... ,m; j=1, 2, ..., n.

Step 6: Each criterion's distance from FPIS and FNIS was calculated with the formulas (10) below:

$$d_{1}^{+} = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_{\underline{j}}^{+}) \qquad i = 1, 2, \dots, m,$$
$$d_{1}^{-} = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_{j}) \qquad i = 1, 2, \dots, m \tag{10}$$

where d_v (...) is the distance between two fuzzy numbers.

Step 7: CC_i, which expresses the distance of the criteria from both the FPIS and FNIS simmultaneously, is defined as sorting alternatives from top to bottom. The CC_i value of each criterion can be calculated using the following formula 11:

$$CC_i = \frac{d_i^-}{d_i^+ - d_i^-}, \qquad i=1, 2, \dots, m. \tag{11}$$

Step 8: A ranking was made among the alternatives by scrutinizing the CC_i values. Therefore, as the alternative Ai approaches 1, it will move closer to the FPIS and away the FNIS.

3. Application

In this section, prioritizing the proposed strategies to reduce air pollution from ships in and around of the Strait of Istanbul and the sensitivity level measurement of the ships passing through the strait by the hybrid fuzzy AHP-TOPSIS method were described step-by-step. Thus, the problem is expressed by emphasizing the special situation of the Strait of Istanbul. The competency levels of the experts whose opinions were taken for analyses were introduced and the application steps of the method described in the previous section for the solution of this problem were explained.

3.1. Problem Description

Air pollution is a major environmental problem threatening human health. The transportation sector, particularly maritime transportation, exhibits a significantly negative contribution to air pollution. For changing or at least limiting this situation, the IMO MARPOL Annex VI (1997) limited the use of fuels that cause a high rate of sulfur emissions. It allows the use of not more than 4.5% content of sulfur fuels worldwide and 1.5% in sulfur emission control areas (SECA). These restrictions, which were implemented for the first time in 2005, have been tighter over the years. According to the rules currently enforced, the ships cannot release more than 0.5% sulfur very-low sulfur fuel oil (VLSFO) worldwide and not more than 0.1% sulfur ultra-low sulfur fuel oil in SECA. However, these rules stated that the ships with scrubber systems can use low sulfur fuels (limited to 3.5% content of sulfur). These rules have made a significant change in the maritime sector and ship owners compete to comply with the rules more quickly. In addition to these strict rules, the IMO has developed major strategies for reducing emissions from the ships and developed basic strategies such as technical (e.g., low sulfur fuel use and on board pollutant abatement systems), operational (e.g., low speed and use of shore-based electricity in port), and market-based (e.g., providing some advantages to the green ships).

Although the implementation of IMO, which is enforced until the first of January 2020, is an essential step for reducing air pollution from ships in many regions with heavy vessel traffic, such as the Strait of Istanbul, this practice may not be enough. Considering the population density of Istanbul City, the impact area of air pollution in the Strait of Istanbul is becoming more serious. In this sense, even though the ships passing through the strait use VLSFO fuels, 0.5% sulfur emissions are threatening the health of the people in the region. Besides, the high price differences between the LSFO and VLSFO and the expectations regarding the continuity of these price levels make the owners prefer the use of scrubbers. Monitoring of the usage of the scrubbers will be difficult, especially in open seas and in areas with heavy vessel traffic.

In this study, additional strategies have been proposed by considering the IMO and EU standards and the ship owner companies' applications to reduce the air pollution caused by the ships in and around the Strait of Istanbul. Table 3 lists these strategies and their definitions. The strategies were first prioritized by taking the experts' opinions and the sensitivity levels of the different ship types to these strategies were then measured.

Table 3. *Strategies to reduce air pollution in Strait of Istanbul and its definitions*

Code	Strategies	CL	Definitions	Example
C1	Declaration of the Strait of Istanbul and the Marmara Sea as a Sulfur Emission Control Area (SECA)	**Technical strategies**	It is stated that the Strait of Istanbul and the Marmara Sea is declared as a SECA. The fuel sulfur content to be used by the ships in this area should not exceed 0.1%.	IMO MARPOL 73/78 Annex VI-designated emission control areas. More stringent requirements are applied in these regions compared to other waters (e.g., North Sea, Baltic Sea, Caribbean Sea, and North America Sea).
C2	Establishment of current detection system		The establishment of the current detection and forecasting system provides the ships with minimum exposure to the counter current and maximum use of the current toward the ship owing to the inclusion of this information in the traffic-planning system. It aims to reduce emissions by using the ship's engine in the most effective way.	The current speed distribution forecast system that is used by NYK within the Kuroshio current near the Taiwan Strait. The system was confirmed to save 9% of fuel consumption [16].
C3	Prohibition of the use of heavy fuel on ships		It emphasizes the prohibition of the use of heavy fuels in the Strait of Istanbul and the Marmara Sea and recommends the vessels to use marine gas oil instead of heavy fuels when passing through these areas.	The Maersk Line began to switch its bunker to low sulfur within 24 miles of California ports in 2006 [16].
C4	Monitoring of low sulfur fuel usage with remote detector systems		To monitor whether the current MARPOL Annex VI requirements are being applied, drone detector systems are to be placed under bridges.	The project named, "Surveillance of sulfur and particle pollution from ships," is co-financed by the Danish Environmental Protection Agency, which performs remote measurements in the Great Belt Bridge.
C5	Optimizing speed limits	**Operational strategies**	Less emission is foreseen because of sailing at lower speeds in the mentioned areas.	Port of Los Angeles-Vessel Speed Reduction Program (VSRP).
C6	Reducing of waiting times of ships		By reducing the waiting time of the ships in the anchorage areas, the emissions during the waiting period are foreseen to be reduced.	A national action could be taken by the Turkish government against air pollution near the Strait of Istanbul according to IMO Res MEPC. 304 (72)/Candidate short-term measures.
C7	Updating the regulations regarding the waiting times in the anchorage areas of the Strait of Istanbul		In the current 168 hours of application, if additional fees will be applied depending on the ship's staying time in the anchorage areas, the waiting time of the ships will reduce and will consequently decrease the emissions.	A national action could be taken by the Turkish government against air pollution near the Strait of Istanbul according to the IMO Res MEPC. 304 (72)/Candidate short-term measures.
C8	Encourage the use of a pilot		With the use of a pilot's experience, it is thought that the emissions will be reduced with the effective use of the ship's engine power owing to minimum exposure to counter current and maximum using of the current toward ship.	A national action could be taken by the Turkish government against air pollution near the Strait of Istanbul according to IMO Res MEPC. 304 (72)/Candidate short-term measures.
C9	Providing the use of coastal electricity for all ships in nearby ports	**Market-based strategies**	It is foreseen that the emissions will be reduced because of the use of coastal electricity by the ships and cruising/passenger ferries in the ports of Istanbul during the time they are alongside the pier.	EU-COMMISSION RECOMMENDATION of May 08, 2006 on the promotion of shore-side electricity for use by ships at berth in Community ports. Port of Kristiansand has supplied shore power since 2018.
C10	Providing financial advantages to ships certifies that they are doing green practices		Providing cost advantages to tolls for ships that certify various additional green applications on air pollution.	The environmental ship index identifies a better performance of ships in reducing air emissions than the current emissions standards. Sweden environmentally differentiated fairway dues program.
C11	Prioritizing direct passing to the ships with certified green application actions		This gives priority of transition to the ships that certify that they are performing various applications on air pollution.	A national action could be taken by the Turkish government against air pollution near the Strait of İstanbul according to the IMO Res MEPC. 304 (72)/Candidate short-term measures.

IMO: International Maritime Organization, MARPOL: The International Convention For The Prevention Of Pollution From Ships, MEPC: Marine Environment Protection Committee, EU: European Union

It is expected that the strategies in Table 3 can lessen the emission rates in the region. Peksen and Alkan [17] revealed that the emission rates in Istanbul City could drop by 53% if the region around the strait would be determined as SECA. Han [16] proposed the establishment of a current detection system and justified that NYK, one of the biggest ship owner companies, had exploited the "Kuroshio current" near the Taiwan Strait to save fuel consumption and indirectly reduce emissions. As a result of prohibiting the usage of heavy fuel oil (HFO) on ships, the Maersk Line started to use fuels with less than 0.2% sulfur content within 24 miles of the California port. Through this, the SO_x and NO_x emissions could be reduced by 95% and 12%, respectively [16]. The port of Los Angeles has implemented the "optimizing speed limits" strategy since 2001 via its Vessel Speed Reduction Program, and with this, the EU [31] forecasted a reduction of CO_2 emissions by 17%-34%. "Cold ironing", which uses coastal electricity in ships, can decrease CO_2, carbon monoxide, and nitrous oxide emissions by over 50%, 99%, and 50%, respectively, according to the report published in the Official Journal of the EU [32]. The Sweden Environmentally Differentiated Fairway Dues Program provides financial advantages to ships certifying that they are doing green practices, which aimed at decreasing the whole harmful emissions by about 75% [33].

3.2. Identification of the Experts

Pollution reduction strategies are intrinsically qualitative processes and it would be more appropriate to consult opinions from experts in identifying these strategies. To have a better understanding of these strategies, it is important to express the opinions of experts quantitatively on these qualitative strategies. This also requires careful selection of the most appropriate experts on this matter. All the selected experts are oceangoing masters, making it easier for them to estimate the effect levels of the related strategies. Their long service time adequately enables them to know the strategies applied in other international channels or straits. In this study, five experts were marine pilots, vessel traffic operators, and academicians. Four of them stay in the Strait of Istanbul as a marine pilot or vessel traffic operator and have at least 10 years work experience. One of them is a professor and had conducted studies on the ship emissions around the Istanbul City [34,35]. He was also assigned as the Head of Istanbul Metropolitan Municipality Department of Environmental Protection and Control. Table 4 presents detailed information about the selected experts, who were asked on which strategies stand out from the rest and which types of ships are more sensitive to these strategies.

3.3. Application of the Methods

Istanbul City is one of the most populated cities and has one of the heaviest maritime traffic owing to the Strait of Istanbul. This consequently increases air pollution and thus requires urgent actions. As a solution, this study proposed strategies for reducing air pollution from ships passing the Strait of Istanbul. First, the priority levels of these strategies were analyzed via the fuzzy AHP method by receiving the experts' opinions. The analysis results (Table 5) determined the overcome power of the implementation of each strategy.

As shown in Table 5, C1 (Declaration of the Strait of Istanbul and the Marmara Sea as a SECA) was seen as the highest priority strategy to reduce the air pollution from shipping activities in the region. As known, ships cannot release more than 0.1% sulfur in SECA, which can result in quality fuel consumption around Istanbul City, tending the experts to prefer this option. C3 (Prohibition of the use of HFO on ships) had become the second highest priority strategy, which can be associated with the highest priority strategy. The experts turned to direct, effective strategies in their selection to reduce air pollution. The C4 strategy (Monitoring of low sulfur fuel usage with remote detector systems) follows

Table 4. *General information of the experts*

Expert number	Current job	Adequacy	Current work experience
Expert-1	Marine pilot	Oceangoing master	13 years
Expert-2	Marine pilot	Oceangoing master	13 years
Expert-3	Marine pilot	Oceangoing master	14 years
Expert-4	Academician	Professor	5 years
Expert-5	Vessel traffic operator	Oceangoing master	10 years

Table 5. *Weights of dimensions and criteria for decision-making groups*

Criteria	Fuzzy weight	Rank
C1	(0.147, 0.146, 0.138)	0.144
C2	(0.071, 0.068, 0.068)	0.069
C3	(0.135, 0.137, 0.133)	0.135
C4	(0.114, 0.113, 0.108)	0.112
C5	(0.076, 0.076, 0.076)	0.076
C6	(0.078, 0.077, 0.078)	0.078
C7	(0.072, 0.072, 0.073)	0.072
C8	(0.071, 0.075, 0.079)	0.075
C9	(0.09, 0.092, 0.097)	0.093
C10	(0.07, 0.068, 0.071)	0.070
C11	(0.075, 0.076, 0.079)	0.076

C3 where the experts emphasized that standardizing and controlling applications that improve fuel quality is as important as improving the fuel quality. Alternatively, C8 (Encourage the use of pilot), C5 (Optimizing speed limits), and C7 (Updating the regulations regarding waiting times in the anchorage areas of the Strait of Istanbul) were perceived as important as much as others. However, they were blended in the experts' direct outcome-oriented evaluations.

The selected vessel types for this study are as follows: (1) direct passing ships, (2) calling ships (ships that stay in ports for a while), and (3) ferries. The sensitivity level of these ships to the abovementioned strategies were analyzed by the fuzzy TOPSIS method. The analysis showed that the direct passing ships had the highest sensitivity level to the strategies held in this study according to the selected experts (Table 6). The direct passing ship's CC score is more than twice that of the ferries. The second highest sensitivity level was achieved by the calling ships vessel type with a slightly lower CC score than that of the direct passing ships. Finally, the ferries exhibited the lowest sensitive vessel type to the strategies among the vessels passing through the Strait of Istanbul.

3.3.1. Case Study

Istanbul City is one of the largest cities of the region with the following shipping activities: (1) vessels stopped over in ports, (2) vessels passing without stopover, and (3) local maritime traffic. These contribute to air emissions, which pose a threat to the environment. Sixteen port facilities have given service in Istanbul City, but the ports are not solely responsible for dense sea traffic in the city. Istanbul City also has the Strait of Istanbul, which is 17 nautical miles long and with an average of 55,000 ships passing every year, making it a unique waterway in the region. Approximately 150 ships pass through the Strait of Istanbul every day, of which 27-28 ships carry dangerous goods. The Strait of Istanbul has 2,500 local maritime traffic transporting approximately 2,000,000 people. Besides physical, oceanographic, and meteorological elements that restrict the safety sailing in the channel, the Strait of Istanbul is four times denser than the Panama Canal (in terms of the number of ships passing) and has three times heavier traffic than the Suez Canal.

After the analyses, some interesting findings particular to Istanbul City had been obtained. The "Declaration of the Strait of Istanbul and the Marmara Sea as a SECA" had been seen as the most important strategy to reduce the air pollution in Istanbul City. Within the scope of the IMO 2020 restrictions, the IMO determined several marine areas as SECA, which do not include the Strait of Istanbul. If the Istanbul City were to be recognized as a SECA, there would be a quantum jump to increase fuel quality and accordingly reduce the air pollution around the city. Finally, it is revealed that the direct passing ships that pass through the strait via the 16 port facilities located in Istanbul City have the highest sensitivity level to the protective strategies. In Istanbul City, the number of direct passing ships that passes the ports is greater than the number of ships that stay in ports for a while owing to the strategic mission of the strait in the world trade. Nevertheless, the ships' waiting times before passing have been increased from 48 to 168 hours. As a result, the direct passing ships stay around the Istanbul City longer than the calling ships. This situation may increase the sensitivity level of direct passing ships passing through the Strait of Istanbul to the proposed strategies more than the different marine areas in the world.

Table 6. *The fuzzy evaluation of "CC" results*

Vessel type	d+	d-	CC	Rank
Direct passing ships	1.292	3.025	0.701	1
Calling ships	1.760	2.525	0.589	2
Ferries	2.860	1.414	0.331	3

4. Discussion

Han [16] recognized the emissions from oceangoing vessels as one of the major sources of air pollution in the shipping industry. After the author had presented the ships' negative contribution to air pollution, IMO precautions against air pollution from ships were evaluated. Finally, emission mitigation strategies were revealed. Alternatively, Wang et al. [27] proposed strategies to reduce air pollution from ships similar to Han [16]. Additionally, they stated historical developments of these strategies and regional actions against air pollution. In this study, the strategies against air pollution from vessels that were expressed in previous studies and the reports of IMO and EU were collected. Moreover, new regional strategies particular to the Strait of Istanbul were added to the evaluation. The strategies' priority levels specific to the Strait were then analyzed. Finally, the sensitivity levels of different vessel types passing through the Strait to these strategies were determined. As a contribution, this study is the only study that uses an approach to preventive strategies against air pollution from ships in terms of priority perception for the Strait of Istanbul. Additionally, this study is also a unique study that evaluated the adaptation potential level of ships to strategies mitigating air pollution.

Ünlügençoğlu et al. [34] and Ünlügençoğlu and Alarçin [35] estimated emissions that contributed to air pollution around the region of Ambarlı Port, which is the biggest port facility in İstanbul and also one of the biggest ones in Turkey. Alternatively, Dogrul et al. [12] calculated SO_2

emissions caused by the ships passing through the Strait of Istanbul by performing measurements for unsteady and steady cases. They also made short-term predictions by considering different scenarios. Lastly, Bayırhan et al. [11] tried determining the exhaust gas emissions of the ferries passing through the strait. Their proposed model is based on the actual ferry movements and ferry machinery information. The proposed model of this study involved both oceangoing and local vessels. Furthermore, this study has a typical study area compared with others and estimated the sensitivity level of each ship type passing through the strait to aforementioned strategies.

5. Conclusion

The studies on air pollution have substantially increased recently. The most important reason for this increase is that environmental degradation such as global warming and climate changes have become more visible. In addition, the impact of the transportation sector on air pollution is at a considerable level. The share of maritime transport in the global transport industry is much higher than other modes. In this context, the maritime transport sector contributes negatively to air pollution, especially via vessels. In accordance with all these parameters, it has become necessary to take precautions for air pollution caused by marine vessels. For this purpose, the IMO, which is the umbrella organization of the maritime sector, has introduced regulations called “IMO 2020”. In addition to these regulations, the EU has developed certain strategies. Private companies are working day-to-day to comply with these regulations and strategies.

In this study, the strategies to reduce the air pollution that threatens human health were approached across the Strait of Istanbul, which affects densely populated areas. Relevant strategies were determined considering the standards set by IMO and EU. These strategies and alternatives were evaluated by selected experts who are employed as a marine pilot, a vessel traffic operator in the Strait of Istanbul, or an academician with studies on ship emissions. These evaluations were expressed mathematically using the fuzzy AHP-TOPSIS hybrid method. Based on the results, C1 (Declaration of the Strait of Istanbul and the Marmara Sea as a SECA), C3 (Prohibition of the use of HFO on ships), and C4 (Monitoring of low sulfur fuel usage with remote detector systems) were the predominant strategies, which show that the experts approached the problem in a realist way and emphasized the strategies related to the use of high-quality fuels as an exact solution. However, C8 (Encourage the use of pilot) and C7 (Updating the regulations regarding waiting times in the anchorage areas of the Strait of Istanbul) were ignored by the experts. Accordingly, it can be concluded that the use of a marine pilot will not adequately reduce the use of the main engine, and the emissions made by the ships through the auxiliary machine while waiting at anchor are not considered remarkable. In line with the strategies prioritized by the experts, the direct passing ships were determined as the most sensitive alternative to these strategies. Since the calling ships and ferries do not use heavy fuels while maneuvering along the strait, they are observed to be less affected by the related strategies than the direct passing ships. Moreover, the direct passing ships use their main engines more than the others during their stay around Istanbul City. Thus, the restrictions of the proposed strategies directly affect the direct passing ships, and their sensitivity levels accordingly increase.

These results develop a perspective for the Strait of Istanbul concerning the air pollution that stems from the vessels. Relevant strategies and alternatives provide a basic perspective for further studies. New studies can be produced by updating the number of alternatives, strategies, and experts or by comparing them with other methods (e.g., fuzzy VIKOR, PROMETHEE, and ELECTRE).

Authorship Contributions

Concept design: U. Bucak, T. Arslan, H. Demirel, A. Balın, Data Collection or Processing: U. Bucak, T. Arslan, H. Demirel, A. Balın, Analysis or Interpretation: U. Bucak, T. Arslan, H. Demirel, A. Balın, Literature Review: U. Bucak, T. Arslan, H. Demirel, A. Balın, Writing, Reviewing and Editing: U. Bucak, T. Arslan, H. Demirel, A. Balın.

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Assessment of Arctic and Antarctic Sea Ice Condition Differences in the Scope of the Polar Code

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Abstract

Polar regions face increasing challenges resulting from the interactions between global climate change, human activities, and economic and political pressures. As the sea ice extent trends diminish, maritime operations have started increasing in these regions. In this respect, an international concern has arisen for the shrinking of sea ice, preserving the environment, and passengers' and seafarers' safety. The International Maritime Organization has enforced the Polar Code (PC) for the ships navigating in these challenging Arctic and Antarctic waters. Polar regions are similar in some aspects but exhibit significant differences in geographical conditions, maritime activities, and legal status. Therefore, the PC that applies to both regions should be reconsidered, accounting for the differences between the areas for further development. This study considers the Arctic and Antarctic geographical differences relevant to the PC's scope. The emphasis is placed on the changes regarding the sea ice extent and sea ice condition differences in the two regions, which are essential in maritime safety. This study also addresses the aspects of the PC that need improvement.

Keywords

Polar regions, Sea ice change, Maritime activities, Polar Code, Maritime safety

1. Introduction

The Arctic and Antarctic regions are the coldest places on the planet. Nevertheless, their environments are shaped by different forces. The Arctic region consists of a partly ice-covered ocean surrounded by the land areas of the eight Arctic countries. It is most commonly defined as the region above the 66° 33' N latitude parallel [1,2]. On the other hand, the Antarctic is a frozen land encompassed by the Southern Ocean, which is situated south of the 60°S latitude parallel [3]. There are notable variances between them. For instance, the Antarctic sea ice forms a symmetric circle around the south pole, whereas the Arctic sea ice is asymmetric through some longitudes as a result of the effects of the ocean currents and winds [4,5]. The Arctic sea ice is not as mobile as that of the Antarctic and is sometimes stationary for more than five years. On the other hand, the Antarctica sea ice does not stay on for ages or thicken as much as that in the Northern hemisphere [5,6]. Thus, the sea ice thickness and volume vary notably within both regions. The Antarctic sea ice is characteristically one to two meters thick, while a large part of the Arctic is two to three meters thick.

Although geographical and seasonal differences exist, both the Arctic and Antarctic are especially susceptible to the impacts of global climate change with the reduction of the sea ice volume and extent [7-11]. The primary cause for the decline is the increase in global mean temperatures linked to climate change. A large amount of ice loss in summer has been accelerated by warmer air temperatures that have resulted in a delay in the freezing of polar waters [12]. Some studies reveal that the Northern Hemisphere may become ice-free in summers soon [11,13,14]. On the other hand, increases in the Antarctic annual average sea ice coverage reached their highest record in 2014 according to the 1979-2018 satellite passive microwave records. However, this was followed by a sharp decline leading to the lowest value being

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measured in 2017 [15]. Notably, sea ice prediction models and studies indicate that the Arctic sea ice extent (SIE) has been decreasing at an alarming percentage since 1990, whereas the Antarctic region trends have been different.

The melting rates explained above create less sea ice, presenting maritime opportunities, particularly in the Arctic [16]. Potential Arctic sea routes between the Atlantic and Pacific oceans serve as new passages for international maritime transportation organizations that provide financial and time savings due to the shorter distance between the East Asia and Western Europe voyages [17]. Although the transit numbers are still few today, the number of operations has been rising [18]. The Northern Sea Route (NSR) will become an available course for open water ships, and the probability of transit will increase by approximately 94-98% between 2040-2059 [19]. Moreover, a research regarding the transportation in the Arctic proves that the NSR could be a good alternative route for global logistics [20]. Additionally, two types of shipping activities are expected to grow in the Arctic region: (1) transit shipping, travel, and transfer of goods from one port to another; and (2) regional shipping to exploit natural resources. Once there are more open waters, the Arctic may witness a boost in traffic with the growth in the extraction of the natural reserves. For instance, there is already an increasing amount of oil and gas transport traffic in the Barents Sea, tourism traffic in Svalbard, and local fishing in Canada's northern waters [21,22]. The exploration of vast oil and gas resources will pave new opportunities in the Arctic for international operators to expand icebreaker fleets and invest in ice-class ships. On the other hand, a significant increase has been observed in large and small passenger ships, private yachts, fishing vessels, and research vessels [23,24]. For instance, the trends in visiting these remote areas by passenger ships to seek out unique ecosystems and species have been facilitated by tourists [25]. On the other hand, Antarctic resources are protected by the Antarctic Treaty (AT) signatory countries, which recognize tourism and fishing as the only profitable activities [26,27]. Additionally, AT consultative and observing countries enter the region in their vessels to conduct scientific studies in Antarctica. As the number of vessels increases because of the situation created by lower quantities of sea ice, numerous environmental and maritime safety issues have been developed [28]. Maritime activities are dangerous and pose a threat to sensitive polar ecosystems and vulnerable marine wildlife and habitats. Moreover, the polar environment's harshness presents significant risks such as floating ice, thick fog, and polar storms that may cause ice damage or stocking in the ice, running aground, and machinery malfunctions. Thus, the risks and hazards of extreme circumstances of the polar regions should be grasped to take advantage of commercial benefits [29]. Ice navigation research also highlights challenges that involve the interpretation of sea ice conditions, weather, ship classifications, icebreaker assistance, and crew experience [30]. An investigation of maritime accidents in the polar regions revealed that the accidents have mostly been related to sea ice, which are further categorized as ice floe hit, being trapped by ice, and ice jets [31]. On the other hand, navigational challenges and the risks for the ships operating in the polar regions are pointed out by authors as route selection problem, root cause analysis of Arctic marine accidents, and navigational risk assessment of Arctic navigation [32-34].

The existence of sea ice limits maritime operations at high latitudes in both hemispheres. Thus, it is essential to know the characteristics of sea ice and its formation, and monitoring and producing sea ice forecasts is crucial to support maritime operations [35]. The Polar Code (PC)'s efforts to mitigate the hazards and reduce risks to the environment elevate "seaworthiness" to a higher standard [36]. However, there is a single mandatory PC for both polar regions. Although the preamble of the PC notes the differences between the two areas, our study argues that some significant differences regarding the sea ice have not been evaluated in the content. The questions are, what are these differences and what are their interactions with PC. This study provides an overview of the differences of the Arctic and Antarctic sea ice conditions via remote sensing data analyses in the PC's scope. This study indicates the inadequacies of PC with some evidences of the impacts of the ice conditions for ice navigation for further studies. Consequently, this study declares the research gaps for further studies on the polar regions' maritime safety.

2. Study Area

2.1. Sea Ice in Arctic and Antarctic

The most apparent difference between the Northern Hemisphere and Southern Hemisphere is their geographical conditions [6,37-40]. The changes in SIE for each hemisphere are clarified in the figures below. Figure 1 (a) and (b) demonstrate an example of the maximum (max) and minimum (min) Arctic SIE based on the data from the National Snow and Ice Data Center (NSIDC).

NSIDC states that the SIE typically covers about 14 million sq km in winter and 5 million sq km in summer. The Arctic reaches the smallest SIE every September and grows to its maximum every March. The Arctic SIE has diminished by about three percent per decade since 1979 [41]. The Arctic sea ice thickness in summer has also declined dramatically from 3.64 m in 1980 to 1.89 m in 2008, exhibiting a total decrease of 48% in thickness [37]. However, as the ice sheets are more likely to crash into each other, a thick ridge ice occurs. The ridge ice does not generally melt during summer and continues to grow the following autumn. The Arctic SIE was 14.78 million sq km on March 20th, 2020 and 4.15 million sq km on September 18, 2019, which are 650,000 sq km and 2.10 million sq km below the 1981-2010 average min. extent, respectively [42]. Recent studies indicate that by 2030, the September sea ice cover will shrink to 60%, becoming less than 40% in the 2060s and less than 10% by 2090 [11].

Most of the Antarctic is perennially coated by ice and snow. During winter, an average of 18 million sq km of sea ice exists, but only about 3 million sq km of sea ice remains in the summer. The Antarctic SIE reaches its min. every February and grows to its max. in September as shown in Figures 2 (a) and (b).

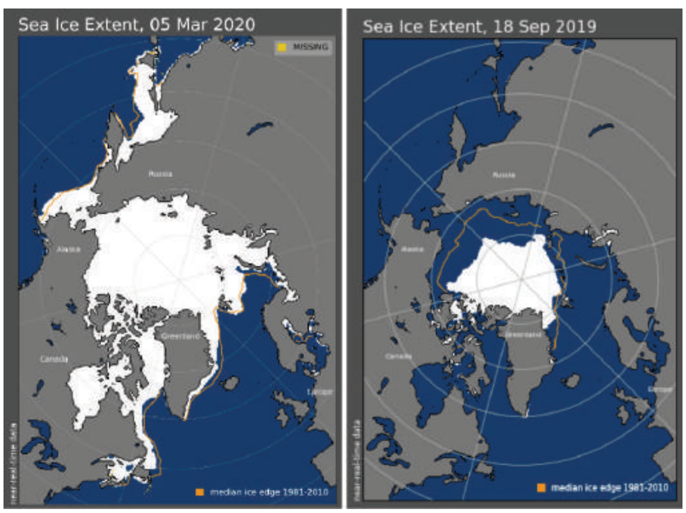

Figure 1. *The Arctic SIE in (a) March 5th, 2020 and (b) September 18th, 2019. The yellow line indicates the SIE in 1981-2010*

Source: Data from NSIDC, 2019 [42]

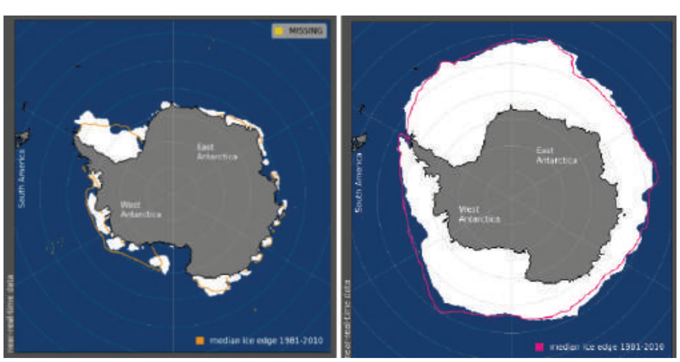

Figure 2. *The Antarctic SIE in (a) February 20th, 2020 (2.69 million sq km) and (b) September 2019 (18.244 million sq km). The yellow line indicates the SIE in 1981-2010*

Source: Data from NSIDC, 2019 [42]

A nearly complete sea ice that forms during winters disperses during summers. The Antarctic annual sea ice max. extent was the second lowest according to the NSIDC satellite record in 2019. Further, the SIE diminished by 13.2% in February 2019 compared to the averaged SIE for all the months of February from 1979 to 2009. The annual min. of the Antarctic SIE is 2.69 million sq km in February 2020 and 18.244 million sq km in September 2019, which are 0.404 million sq km and 0.234 million sq km below the 1981-2010 average min. extent, respectively [42].

Table 1 lists a variety of differences between the Southern and Northern hemisphere's sea ice parameters. Opposite geographical distributions are evident where the Arctic sea ice grows asymmetrically, whereas the Antarctic sea ice remains symmetric. Sea ice can currently exist at 38°N and 55°S in the in the Arctic and Antarctic regions, respectively. Owing to the difference in the sea ice evolution processes, the ice types differ. In the Antarctic, frazil ice is common and columnar surfaces are also found, though more rarely. In the Arctic, the topside of the ice comprises of frazil ice, while the downside is mainly congelation ice [39]. The Arctic ice melts at the air and ice interaction, whereas the Antarctic sea ice usually melts at the ocean and ice interaction. As a result, melt ponds are rarely observed in Antarctica, whereas melt ponds take a large part of the Arctic ice surface [43]. Thick and extensive ice shelves surround 75% of Antarctica's coastline; however, they are not typical for the Arctic [44]. In Antarctica, relatively large ice platelets are produced by the flowing, low salinity water underneath the ice shelves. These ice platelets can be present up to several meters in depth beneath a sea ice sheet. In contrast, platelet ice grows in pools in the Arctic region [45]. While Landfast ice is typically found at water depths in Antarctica, landfast ice in the Arctic comes in direct contact with the seafloor, because most of the shallow areas are sheltered by the ice shelves. Polynyas are divided into two types: (1) open-ocean polynyas and (2) coastal polynyas. Open-ocean polynyas

Table 1. *Polar regions' sea ice differences*

		Arctic	Antarctic
1	**Latitude**	90°N-38°N	55°S-75°S
2	**Geometric distribution**	Asymmetric	Symmetric
3	**Type of ice**	Mainly columnar	Mainly frazil
4	**Melting process**	Air/ice interaction	Ocean/ice interaction
5	**Ice shelf**	Not present	Present
6	**Platelet ice**	Not present	Present
7	**Land fast ice**	Over shallow water	Mainly over deep water
8	**Melt ponds**	Significant	Insignificant
9	**Polynyas**	Coastal	Open ocean

are estimated to occur due to the deep warm water that is mainly common in Antarctica, and Katabatic winds are believed to cause coastal polynyas that are typically found in the Arctic region [46].

2.2. PC

The International Maritime Organization (IMO) undertook work on a code for regulating the ship design, building, and operations in the early 1990s, and the guidelines for ships operating in Arctic ice-covered waters were accepted in 2002 [47]. Nevertheless, these guidelines applied only to the Arctic region and did not include the Antarctic region. Afterward, noteworthy arrangements were made by the IMO in 2009, amending them to cover the Antarctic waters [48]. Finally, the IMO changed the regulations from being mere guidelines to compulsory lawful requirements. This has been a long process for the PC, and it entered into legal force on January 1st, 2017 [49,50]. The PC is structured on the former IMO instruments and consists of two parts: Part I, introduction and safety measures and Part II, pollution prevention measures. Part II consists of five chapters that will not be evaluated in this study. Within the scope of PC, the sources of the hazards in the polar regions have been identified as ice, low temperature, periods of darkness and daylight, remoteness, and lack of accurate information and crew experience [50].

Consisting of 12 chapters, Part I of PC focuses on the safety of shipping in the polar waters and addresses a wide range of safety measures, including the need for ships to have a polar certificate and requirements according to the types of ships and ice conditions. Ships are categorized according to their design properties in different ice conditions. Every ship to which the PC applies shall have a Polar Ship Certificate (PSC) concerning the design and construction of the ships and equipment, crew and passenger clothing, ice removal, and fire safety. To support in the decision-making process, the Polar Water Operational Manual (PWOM) was developed to provide standards for vessels and crew, information about the ship's specific operational capabilities, limitations, and procedures to be followed in normal operations and in the event of incidents [50]. Other chapters of Part I include the ship structure, subdivision and stability, watertight and weathertight integrity, machinery installations, fire safety/protection, life-saving appliances and arrangements, the safety of navigation, communication, voyage planning, and manning and training. Additionally, the polar operational limit assessment risk indexing system is a significant tool for assessing the ships' operational limitations and risks of navigation in ice. It is similar with the PSC and PWOM, but it is not a mandatory requirement. Its limitations are the human factor, the frame of application, and legal status [51]. According to a PC research, shortcomings are stated that it does not exclude fishing and leisure vessels, it does not propose advanced training for all crew members, and the pollution risks are not adequately addressed. Additionally, it does not consider the crew's experience, and all Arctic aspects such as light ice conditions and ships without ice class are treated insufficiently [52].

3. Methodology

Sea ice observations have been carried out in the ships and coastal stations for more than 100 years. However, considering the remoteness of the Arctic and Antarctic regions, *in situ* measurements are not practical. For this reason, the satellite era, which gained momentum at the beginning of the 1960s, has become the most crucial observation method for the polar regions. Data from the satellites are utilized widely in research and in monitoring the SIE and other parameters [35,53].

The evolution of remote sensing systems for satellites commenced with the launch of the Russian Cosmos-243 satellite in 1968. Later, The National Aeronautics and Space Administration (NASA) launched the electrically scanning microwave radiometer (ESMR), which supplied data from 1972 to 1977. However, these satellites could not meet the technical requirements; therefore, development studies continued. With the development of new satellite systems, sea ice data has gained reliability. After the ESMR period, the scanning multichannel microwave radiometer (SMMR) was operated from 1978 to 1987. SMMR more correctly perceived the sea ice concentration extent with at least 15% sea ice. The US's Defense Meteorological Satellite Program introduced passive microwave sensors, special sensor microwave imager (SSM/I), and particular sensor microwave imager and sounder instruments. The first long-term sea ice data was provided for scientists after the introduction of SSMR [54]. In 2003, NASA launched the Ice, Cloud, and land Elevation Satellite (ICESat) to track the sea ice thickness, ice sheet heights, and land cover. Further, the ICESat-2 launched in September 2018 provides a more comprehensive and precise ice thickness valuation, marking a significant development [55]. These instruments have provided the most extended and consistent time series of sea ice data, permitting research on the tendencies of the sea ice conditions in polar regions.

In 1993, NASA contracted NSIDC to serve as the Distributed Active Archive Center (DAAC), which provides a comprehensive data on sea ice, ice sheets, and ice shelves to support research. The NSIDC DAAC archive distribute cryospheric data from NASA and help researchers utilize the data products [54].

4. Results

4.1. Arctic SIE

Figure 3 (a) displays the average monthly SIE values in 1979-2019. The average monthly values from 1979 to 2009 are indicated by the thick blue curve, and the red line represents that of 2019, which remains below the average of 1979-2009 in all months. In the last decade, all values remained below the average and each year exceeds the recorded value of the previous year. In Figure 3 (b-c), the average monthly SIE every March and September between 1979 to 2019 is indicated when the Arctic ocean begins to freeze and melt, respectively. The SIE in the Arctic region in March and September declines at a rate of 2.6% and 12.85% per decade, respectively. The linear trendline shows the steady decrease of the Arctic SIE for both months with the most significant decline experienced in September. As a result of this decreasing trend, the periods when the sea ice begins to freeze lengthen. September receives the most attention because it is the month with the least SIE.

4.2. Antarctic SIE

Figure 4 (a) displays the average monthly Antarctic SIE in 1979-2019. The thick blue curve indicates the average monthly SIE values from 1979 to 2015. Figure 4 (b-c) shows the average monthly Arctic SIE every February and September from 1979 to 2019. The SIEs in February and September 2017 are the lowest in the last decade. The Antarctic SIE values for February over the years are even lower than those in the Arctic in September. Further, the Antarctic SIE values for September are well above the Arctic max. SIE. The Antarctic monthly and annual SIE values (for

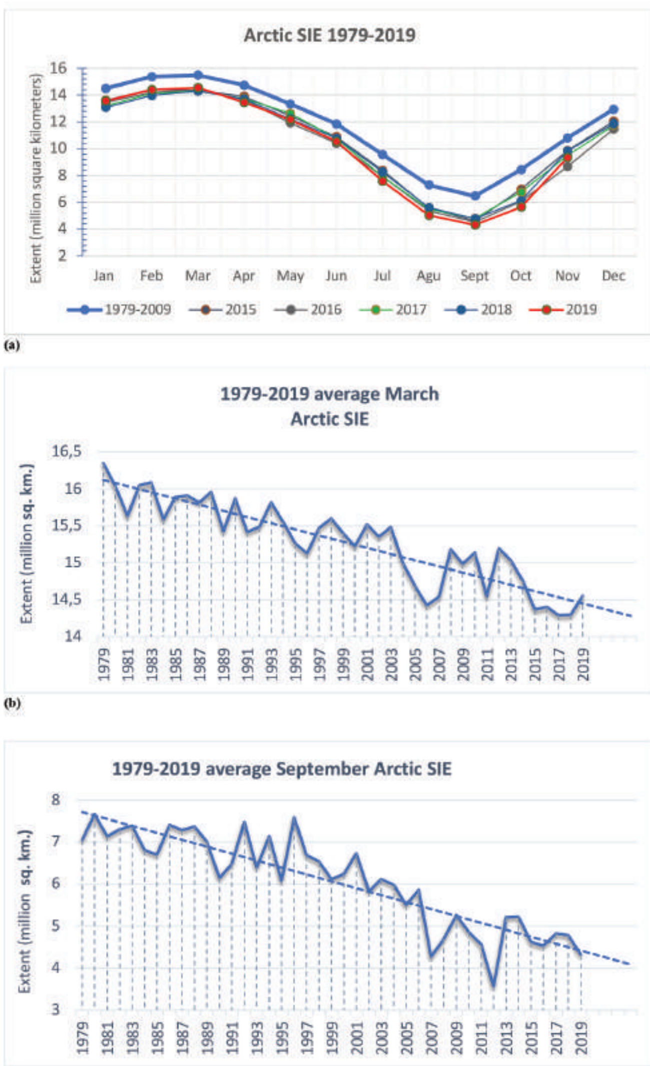

Figure 3. Arctic SIE in (a) in 1979-2019, (b) average in March 1979-2019, and (c) average in September 1979-2019

SIE: Sea ice extent

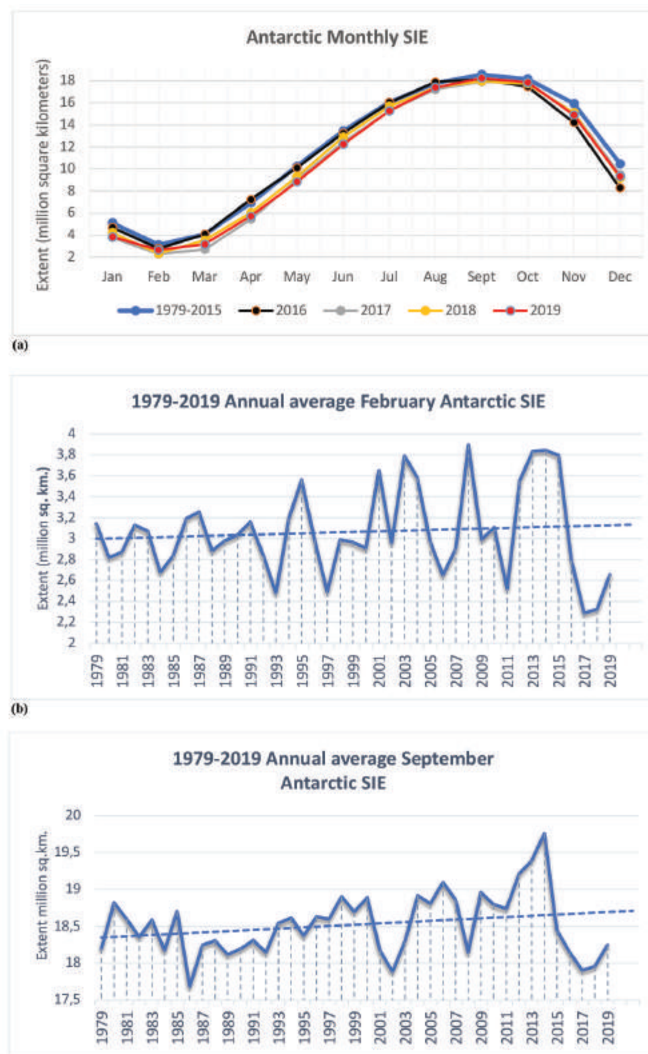

Figure 4. Antarctic SIE in (a) 1979-2019, (b) February 1979-2019, and (c) September 1979-2019

SIE: Sea ice extent

the 41 years of the dataset, 1979-2019) indicate trends until 2014. Following that, a low record in three years is reached. The Antarctic min. monthly ice extent always occurs in February and is still less than five million sq km.

As seen in Table 2, both polar regions reach their max. during winter and shrinks down to the min. during summer. The Arctic min. SIE in September 2012 and the max. SIE March 2017 extents have been the lowest recorded SIE by the satellite for 41 years. The lowest min. Arctic SIE was 3.56 million sq km in September 2012 and reached its second lowest recorded value in 2019. In 2019, the ice extent diminished by 33.23% and 6.1% compared to the average in September and March (1979-2019), respectively. The lowest monthly average Antarctic SIE was 2.288 million sq km in February 2017, and the lowest recorded yearly average for the same was 10.75 million sq km in 2017. Snow thickness creates a big difference between both poles, reaching a considerable thickness in Antarctica as compared to the Arctic snow cover. Further ice thickening may be caused by snowfalls as well as melting and refreezing of snow. Sea ice thickness varies considerably within both regions. While the typical sea ice thickness of the Arctic is above two meters, the Antarctic sea ice is characteristically below the two-meter range. Multiyear ice, which has survived more than one melting season, is three meters thick or more and firmer than the one-year ice. A large part of the Arctic Ocean is composed of multiyear ice, where most of it occurs as pack ice. Resultantly, the strength of the ice is higher in the Arctic, which is vital for navigation. The average Arctic multiyear ice has significantly reduced from 1979 to 2019. The Antarctic mainly consists of seasonal ice that freezes and melts in a season and remains in a few coastal regions.

5. Discussions

The development of the PC and its importance and shortcomings for ice navigation are introduced in section 2.2. Although the PC states that the differences were taken into consideration in its efforts to adapt the Antarctic region, the changes and differences revealed in this study should be considered for the further development of PC.

The study related to navigational risks in ice-covered waters emphasizes the importance of environmental factors such as ice thickness, ice formation, weather conditions (e.g., wind, fog, visibility, and temperature), the drift of pack ice, floating ice floes, and ice restrictions, which affect the vessel's movement and etc. [32]. Because it is being surrounded by land, the sea ice stays in the Arctic water, while the opposite condition occurs in the Antarctic. Additionally, the SIE and volume are diminishing more rapidly in the Arctic than in the Antarctic. These are essential parameters regarding the ships' operational capabilities. Some crucial questions to be considered are where the ice is and where it is drifting, what kind of ice it is, how thick and strong it is, and whether there are icebergs. Within these questions' framework, different applications should be made for both regions depending on the sea ice conditions.

The area of the PC is also geographically limited. It can be extended to sea ice concentrations with a coverage of one-tenth or higher. The PC's Arctic boundary should be changed to cover the sea ice's edge of the 1979-2010 line, rather than the 60°N line [56]. As mentioned in previous sections, maritime activities in the Antarctic region involve passengers, fishing, research, and re-supply ships, whereas those in the Arctic include various types of vessels in operation. As an outcome of the implementation of the PC, patterns of activities are expected to differ within the Arctic and Antarctic regions. Additionally, while there has been

Table 2. *Arctic and Antarctic SIE differences*

		Arctic	Antarctic
1	**Max./Min. SIE months**	March/September	September/February
2	**Max. SIE**	16.342x10^6 km^2 (March 1979)	19.756x10^6 km^2 (September 2014)
3	**Min. SIE**	3.566x10^6 km^2 (September 2012)	2.288x10^6 km^2 (February 2017)
4	**The trends in SIE; 1979-2019**	Significant decrease	Small decrease
5	**Snow thickness**	Thinner	Thicker
6	**Mean thickness**	1976: 5 m	0.5-0.6 m
7	**Typical thickness**	>2 m	<2 m
8	**Strength of ice**	High	Low
9	**The age of ice**	Largely multiyear ice	Largely one-year ice
10	**The average multiyear ice area**	1979 to 1996; 5.531×10^6 km^2, 1997 to 2016; 4.226×10^6 km^2	3.5x10^6 km^2
SIE: Sea ice extent, Max: Maximum, Min: Minimum			

an increase in the Arctic maritime activities, no significant increase in the traffic density is observed in Antarctica in recent years. The number of unique ships entering the Arctic PC area in the month of September from 2013 to 2019 has increased by 25% (1298 to 1628 ships), and the total distance sailed by all vessels increased by 75% [57]. Besides, many vessels that are currently operating in the polar regions are the non-parties to The International Convention for the Safety of Life at Sea (non-SOLAS), which means that the vessels are not compliant with PC and may present risks.

There are several definitions of sea ice for navigation. As mentioned in previous sections, 30% of Arctic sea ice is multiyear ice (3 m or thicker), while the Antarctic mainly has first-year ice (0.3 m-2 m thick). First-year ice may damage the vessel's hull and multiyear ice impact may exceed the force of the vessel's strength. On the other hand, if the vessel's machinery power is limited, drifting ice can easily collapse and the vessel might beset in the ice. Moreover, the drift ice motion takes place differently even within each region [58,59]. There should be up-to-date ice information for masters sailing in the polar regions to make tactical navigation decisions.

On the other hand, the goal of PC Part I, Chapter 11, "Voyage Planning," is to ensure sufficient information for the safety of the ships, the crew, and the passengers and to protect the environment. One of the most critical issues in this chapter is that the master shall consider a route, taking into account the areas that are remote from search and rescue (SAR) capabilities. The remoteness, lack of infrastructure and assets, lack of accurate charting, and the harshness of the environment make the emergency response and SAR operations significantly more difficult in the Antarctic. Additionally, it is highlighted in the Council of Managers of National Antarctic Programs report (SAR Workshop IV SAR Coordination and Response in the Antarctic) that although there are significant differences between the polar regions, there would be best practices to learn from Arctic SAR agencies [60]. Moreover, multiple criteria such as regulations and restrictions, traffic congestion, charges, route length, sea depth, weather, and sea conditions are the critical factors for voyage planning, which differs in two regions [61]. For instance, the ice-strengthened passenger ship M/S Explorer was the first ship that sunk in the Antarctic waters following a collision with ice in 2007. According to the incident report, the primary cause was the ship captain's misjudgment of ice where they were countering. Even though he worked in the Baltic Sea, the Antarctic ice conditions have shown to be rather different from those in the Baltic [62,63].

The human factor in the polar regions is crucial and experienced people are needed. The human element was the primary contributor to the total number of accidents (roughly 77%) due to inattention, heavy weather, age, and lack of communication [24]. Seafarers are usually inadequately trained to deal with polar conditions [30,64]. PC Part I Chapter 12, "Manning and Training," aims to ensure adequately qualified, trained, and experienced personnel. There should be a curriculum that addresses the polar regions' differences for ice navigation in polar waters in basic and advanced level training.

6. Conclusions

This study analyzed the SIE changes in the Arctic and Antarctic regions based on the NSIDC datasets. After reviewing the 41-year satellite records, SIE's variations indicated a long-term trend of reduction from 1979 to 2019. Although some studies have demonstrated these lessening outcomes, our analysis takes a precise approach regarding the differences in the PC's scope. The differences in the Arctic and Antarctic sea ice characteristics were compared within some limitations. Because the results are obtained through remote sensing data analysis, they represent changes in ice conditions observed by satellites only. The differences observed according to the formation processes and features of sea ice that concern navigation have been introduced. As explained in the methodology chapter, SIE changes measured from the data obtained from various satellite and remote sensing systems were interpreted for both regions in our results. In the discussion section, some critical issues arising from the sea ice condition differences in ice navigation were pointed out. Our study confirms that the PC should be improved. For further studies, researchers should consider the density traffic of the vessels excluded in the PC. Considering the results of this study, maritime safety tools can be generated separately for the polar regions. PC Part II, Pollution prevention measures, should also be evaluated differently, which are the research gaps to be developed for the polar regions. Regardless, this study's investigation points to the need for future improvements of the mandatory PC for each polar region separately.

Authorship Contributions

Concept Design: M. Karahalil, B. Özsoy, Data Collection or Processing: M. Karahalil, B. Özsoy, Analysis or Interpretation: M. Karahalil, B. Özsoy, Literature Review: M. Karahalil, B. Özsoy, Writing, Reviewing and Editing: M. Karahalil, B. Özsoy.

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How Ports Can Improve Their Sustainability Performance: Triple Bottom Line Approach

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Abstract

Ports, located at the center of the world trade, are shown to be one of the harmful industries to the environment due to their characteristics such as the amount of waste they produce, harmful emissions, and noise pollution they cause. That makes ports also one of the important industries to reduce this harm caused by itself. In order to work toward reducing this harm, it is thought that the factors that cause the most damage should be determined first, then the steps for reducing the damage caused by these factors should be found. Hence, to detect the degree of importance of port sustainability criteria and decide the sustainability performance of the chosen port is determined as the primary aim of this study. In order to achieve this objective, the sustainability performance of an international port has been examined for seven years, based on financial, environmental, and social dimensions of sustainability with the analytical hierarchy process and technique for order preference by similarity to ideal solution methods. Accordingly, the possible reasons of port sustainability performance inequalities for all three dimensions of sustainability have been discussed. This study concludes that "materiality model" and "Fatal 5 program" developed by APM Terminals have remarkable positive effects on sustainability performances of ports.

Keywords

Port sustainability, Sustainability performance measurement, Multicriteria decision making

1. Introduction

Sustainability has become a policy concept with its inclusion in the 1987 Brundtland Report [1]. Since then, several areas in academic literature such as social sciences, managerial sciences, environmental science, or technical science have defined the term in line with their expertise. Hence, it is possible to find various definitions of sustainability in literature [2]. However, finding a consistent definition of sustainability in literature is still one of the biggest challenges as most of the sustainability studies do not serve a definition of sustainability, even they evaluate it [3]. In its simplest form, sustainability concept is the management of all sorts of resources to continuing at least quality of life for the current generation and also for future generations [4]. The most cited sustainability definition was created in 1987 in the Brundtland Report, which is; "Meeting the needs of the present without compromising the ability of future generations to meet their own needs [5]".

In addition to the lack of a clear and agreed sustainability definition, environmental and financial dimensions of sustainability are considered rather than social dimensions [6]. In 1997, Elkington [7] revealed the need to evaluate the performance of three basic dimensions of sustainability, i.e., environmental, economic, and social dimensions, to make sustainability operational and named this as the "triple bottom line approach". The environmental sustainability term was presumably invented by the World Bank scientists although, the term "environmentally sensitive development" was used in the beginning [8]. The environmental dimension of sustainability includes the reduction of people's negative impacts on environment and protection of nature and ecosystems. Environmental sustainability emphasizes renewable and non-renewable resources globally, and human beings must act sensitively to the use of all resources [9]. Value creation and the financial situation of firm's sustainability activities and their impacts on the company are two main focus areas of the financial dimension of

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sustainability [10]. Financial sustainability concerns the cost-benefit analysis of an industry that aims to be profitable while producing products and services that contribute to society [11]. Some economists simplify the definition of financial sustainability concept as "maximization of the benefit from consumption and the increase of wealth [12]." The social dimension of sustainability primarily focuses on human development. It also deals with cultural and social necessities like the permanent establishment of basic requirements such as food and shelter, security, equality, health, freedom, education, and employment [9].

2. Literature Review

Port sustainability issues have been studied in many different fields of sustainability such as development, performance, management, port construction, sustainability indicators, reporting, measurement, etc.

Daamen [13] analyzed sustainable development in ports within the USA and Europe; he took Rotterdam and Hamburg ports and these cities as a sample with the aim of "finding a new typology and new interpretation of the contemporary port-city interface". At the end of the study, the author demonstrated about the Hamburg and Rotterdam cities port-city interface situations and found two objectives which are to attain public support in order to achieve short and long term objectives and to determine the realization degree of these objectives on the local level. A case study conducted by Abood [14] in 2007 that took New York port as a case and demonstrate how to fit more advanced programs into a sustainability framework using determined eight operational topics "dredging, ballast water, habitat restoration, air quality, water conservation, energy conservation, material conservation and waste handling". As a result, the author proposed a rating system in line with given operational topics and designed only for port activities [14]. Lam and Van de Voorde [15] worked on the sustainable development identifiers and determined the influence degree of these identifiers of sustainable development for port cities with their survey, conducted with 381 people at Torkaman city. As a result, civil rights were determined as the most effective, while political identifiers were determined as the least effective ones [15].

Multicriteria decisions making (MCDM) methods were used by Lirn et al. [16] to measure the port sustainability performance with the sample of three major container ports in China. The most critical port sustainability indicators determined in this study as "avoiding pollutants during cargo handling and port maintenance, noise control, and sewage treatment [16]".

In 2005, Peris-Mora et al. [17] proposed a new environmental sustainability system for ports and created sustainable environmental management indicators system. They proposed seventeen indicators based on their results from case studies and multicriteria analysis methods [17].

3. Methodology

MCDM is a method that used in sustainability studies, especially the ones that measure sustainability performances. MCDM methods, defined by Çınar [18], as the whole set of procedures that try to help the decision makers to reach the solution wanted by addressing complex decision problems in a scientific and analytical framework. Also, it is extensively used to solve the problems of multiple and conflicting goals [19]. To measure sustainability performance, indicators are developed and used predominantly [20], providing a useful framework while evaluating multiple variables together in one of the features of MCDM methods. Thus, analyzing the three dimensions of sustainability together can be achieved with these methods [21]. In the present study it has been decided to use MDCM methods.

In this study, APM Terminals is chosen as a case company, first started to serve as a general cargo facility in Port of New York in 1958, and was officially established as an independent division in Maersk in 2001. Today, it operates as one of the world's most comprehensive port networks with 78 terminals and 22,000 industry professionals globally [22]. Thus, it is considered that the selection of the sample company will represent the port sustainability activities in the world in the most comprehensive way possible. Also, its sustainability and annual reports can be obtained from their main website, and the subsequent data about main sustainability criteria can be accessed from the reports between 2011 and 2017. After 2017, their reporting policy has changed, and they started to publish their data as Maersk Group. Hence the data between 2011 and 2017 has been used in this specific study.

To reach the aim of the study, as defined to detect the importance of the degree of port sustainability criteria and decide the port sustainability performance of the chosen port, at first, indicators that focused on port sustainability measurement in current literature have been examined. Then, sustainability and annual reports of seven years period of the chosen international port have been analyzed to obtain data that meet indicators compiled from the literature. Besides, the financial, environmental, and social dimensions of sustainability are examined in sustainability performance measurement. Six indicators of environmental dimension [Greenhouse gas (GHG) emissions, sulfur oxides emissions (SOx), nitrogen oxides emissions (NOx), water consumption, electricity consumption, fuel consumption], one indicator of financial dimension (Revenue), and two indicators of social dimension (Fatalities and injury/

sickness) are the suggested port sustainability indicators in the literature by [17,23-25]. Other indicators used in the analyses compiled by the author via sustainability and annual reports of the port. In order to measure these dimensions, fifteen indicators in total were used as measurement values, including four financial, six environmental, and five social dimensions. Port sustainability dimensions gathered from the literature are given in Table 1.

With these indicators, the sustainability performances of port measured via the analytical hierarchy process (AHP) and technique for order preference by similarity to ideal solution (TOPSIS) methods from MCDM. First, the AHP method is used to determine the weights of sustainability subdimensions, then the reduction of multidimensional data to a single dimension is ensured. After the AHP process, using the TOPSIS method, the most successful years and indicators are achieved on a yearly basis for each main dimension of sustainability and discussed the possible reasons for these successes.

In MCDM problems, the judgments about the subject are learned by discussing with the persons concerned about the subject via evaluation forms. In order to obtain consistent outcomes, the interviewees need to be expert or moderately expert about the subject. Consequently, the results of the AHP are based entirely on the judgment of these persons [26,27]. Once the dimensions of sustainability have been identified, an evaluation form has been prepared, containing three dimensions of sustainability for consultation. These evaluation forms were filled by industry experts and academicians. Within the scope of the study, 10 experts were interviewed. The experts who completed the evaluation form consist of academicians experienced in sustainability and port subjects, finance and banking sector employees, environmental and chemical engineers, and they were interested in sustainability and job security. Within the scope of the study, data collection forms related to their field of expertise were sent to each expert, allowing each expert to make binary comparisons related to their field of expertise. Afterward, the method was continued by taking the geometric average of the data obtained for each dimension during the application of the AHP method. Detailed information about these experts who helped in the AHP weighting process of the study is given in Table 2.

Table 1. *Dimensions and subdimensions of port sustainability*

Environmental dimension indicators		Financial dimension indicators		Social dimension indicators	
Env_1	Greenhouse gas emissions	Eco_2	Revenue	Soc_1	Number of employees
Env_2	Sulfur oxides emissions	Eco_2	Profit for the year	Soc_2	Ratio of women employees to total number of employees
Env_3	Nitrogen oxides emissions	Eco_3	Tax for the year	Soc_3	Ratio of women employed in senior management to total number of employees
Env_4	Water consumption	Eco_4	Operating Profit	Soc_4	Fatalities
Env_5	Electricity consumption			Soc_5	Lost-time injury and sick leave accidents
Env_6	Fuel consumption				

Table 2. *Detailed information about the experts*

Expert area and information about the experts	Environmental dimension (E)	Social dimension (S)	Financial dimension (F)
Port Sustainability (Department of Industrial Engineering, Narvik University College, Narvik, Norway)	√	√	√
Sustainability (Department of Maritime Business Administration, Dokuz Eylul University, Izmir, Turkey)	√	√	√
Port (Department of Maritime Business Administration, Dokuz Eylul University, Izmir, Turkey)	√	√	√
Environment and Job Security (Environmental Engineer and Job Security Specialist in Borusan Mannesmann, Bursa, Turkey)	√	√	
Environmental Sustainability (Chemical Engineer, 4K Kimya Sanayi, Izmir, Turkey)	√	√	
Finance (QNB Finansbank, Izmir Branch Manager, Izmir, Turkey)			√
Finance (QNB Finansbank, Authorized Assistant, Izmir, Turkey)			√
Finance (T.C. Ziraat Bank, Individual Customer Relationship Authority, Bursa, Turkey)			√
Finance (Vakıfbank, Controller, Istanbul, Turkey)			√
Finance (Vakıfbank, Bank Inspector, Kutahya, Turkey)			√

3.1. Mathematical Infrastructure of AHP and TOPSIS Methods

AHP is one of the multicriteria decision making methods in which the eigenvalue approach is used for binary comparisons [26]. The AHP method helps to create consensus by reducing the ideas of a group to a single result and provides the final solution by evaluating the geometric averages of binary comparisons for each variable [26]. In this direction, weights of the criteria [w] were obtained in binary comparisons. Decision makers do not have to make numerical comparisons; they can make a comparison with the words [28]. Binary comparisons usually use the 1-9 scale of Saaty [29], as shown in Table 3.

Table 3. *Importance rating table used in comparisons [29,30]*

Importance rating	Definition	Statement
1	Equally important	Both factors have the same precaution
3	Important in middle grade (less superior)	According to experience and judgment, a factor is more important than the other
5	Important in strong grade (superior state)	One factor is strongly more important than the other
7	Important in very high grade (very superior state)	One factor is strongly more important at a higher level than the other
9	Important in absolute grade (absolute superiority)	One of the factors is very important to the other
2,4,6,8	Intermediate values	The preference between the two factors is the intermediate values of the ratios found in the above explanations
Mutual values	If factor i has one of the above numbers assigned to it when compared to factor j (x), then j has the reciprocal value when compared with i (1/x)	

When the AHP is analyzed, the upper limit is set at 9 (shown in Table 2) as this method produces good results, particularly for n <10 criteria [31]. In other words, while solving MDCM problems with AHP method, the number of criteria exceeds 9, and big inconsistencies can occur.

In the comparison matrix, all comparison values are positive, and diagonal elements take the value 1 as it is compared with the criterion itself [32].

Relative weights are calculated using the w eigenvector based on λmaks, providing the equation as Aw = λmaks.

Besides, two coefficients are used, consistency index (CI) and consistency ratio (CR), to ensure the consistency of subjective perceptions and the relative weights. The following formula 1 is used to calculate CI:

$$CI = (\lambda maks - n)/(n-1) \quad (1)$$

Where λmaks is the greatest eigenvalue and n is the total number of properties (criterion). In order to obtain a reliable result, the CI value must not exceed 0.1 [32]. The CR can be obtained using the following formula 2:

$$CR = CI/RI \quad (2)$$

Where RI stands for "random value index". Table 4 shows RI values of different element numbers (n).

For reliable and realistic results, the consistency ratio (CR) < 0.1 is expected. Some researchers indicated that a maximum number of 0.2 is the maximum acceptable value for this boundary value [32].

TOPSIS method, which is one of the multifeatured decision making methods, enables the values of the examined variables to be converted mathematically into a single score and evaluated as a more concrete output [33]. In this method, alternative options are compared according to certain criteria and ideal distances between maximum and minimum values that the criteria can take. The first step to be used in the TOPSIS method is creating the decision matrix. decision maker demonstrates decision points in rows and columns, showing the factors in this matrix [33]. The decision matrix was then formed, normalized, and the weighing process was completed following the rules of the method. Once the weighted normalized matrix (V matrix) has been obtained, the maximum and minimum values for each column are determined; these values are named ideal solution values and negative ideal solution values [33].

4. Results

Table 5 shows the CR (consistency ratio) values of each dimension.

According to Aykın [34], the CR values must be smaller or equal to 10% to adopt the inconsistency is acceptable. Otherwise, for CR >10%, the results are assumed unacceptable. Hence, for CR value ≤0.1, the comparisons of matrix is considered consistent in AHP method [35], as evident from Table 5.

Table 4. *Random value index [32]*

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 5. *Reliability of results*

	CR value
Dimensions of sustainability	0.020807
Financial dimension	0.039998
Environmental dimension	0.032870
Social dimension	0.053100

4.1. Results of AHP

According to the results, the financial dimension of sustainability is defined as the most important dimension from the perspective of the ports; environmental dimension and social dimension of sustainability followed it, respectively.

Between the subdimensions of financial dimension, operating profit of the ports chosen as the most important one. In environmental dimension, the amount of water consumption in ports and in social dimension, fatalities in ports are seen as the most important subdimensions of sustainability. Figure 1 presents the order of importance and priority vector (PV) values of each dimension and their subdimensions.

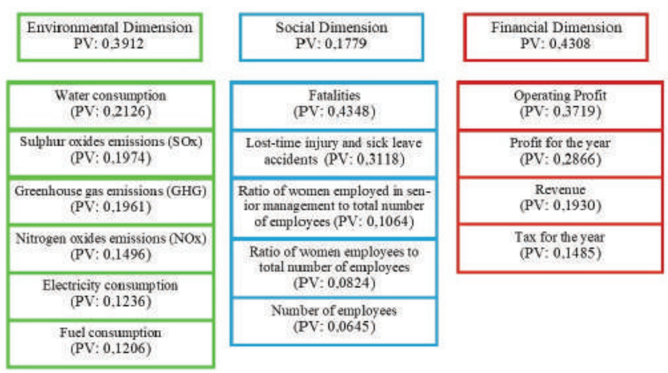

***Figure 1.** Importance degree of port sustainability criteria*

GHG: Greenhouse gas, PV: Priority vector, SO_X: Sulfur oxides emissions, NO_X: Nitrogen oxides emissions

With the analytic hierarchy process, first decision matrices have been created for all dimensions for sustainability. It is the geometric mean results of the binary comparison evaluations of the given experts. Second, normalized matrices have been created, and priority vectors of each dimension and their subdimensions obtained. In order to measure the reliability of these weights of dimensions, CR values of each dimension and their subdimensions have been calculated using the formulas λmax, CI = (λmaks-n)/(n-1) and CR = CI/RI [32]. RI values given in Table 4 have been used to obtain CR values. After defining CR values as reliable, priority vector values of each dimension and their subdimensions were used as criteria weights in the TOPSIS process.

4.2. Results of TOPSIS

After deciding the order of importance and PV values of all dimensions and their subdimensions, annual reports and sustainability reports between the years 2011 and 2017 of APM Terminals were analyzed. The APM Terminals score for each year and each subdimension were identified, and decision matrices of three dimensions of sustainability were developed. Then, normalized matrices were calculated using the values obtained in AHP. After defining ideal and negative ideal solution values, ideal and negative ideal distances were calculated. At the end, the formula Ci^*=(Si-)/[(Si-)+(Si+)] [33] was used to calculate the relative proximity of the ideal solution, and the values obtained by years are shown in Figure 2, 3 and 4.

Based on the values gathered from sustainability and annual reports of APM Terminals and PV values obtained from the AHP, the results of financial sustainability performance of APM Terminals between the years 2011 and 2017 are calculated and visualized, as shown in Figure 2. The results show that 2014 was the most successful year for APM Terminals in the perspective of financial sustainability. After 2014, the financial sustainability performance of the port has steadily declined; the sharp decline of 2017 is particularly noteworthy.

While calculating TOPSIS results of the performance of environmental sustainability of APM Terminals, the values related to subdimensions of the environmental dimension of sustainability were gathered via the annual and sustainability reports of APM Terminals. However, subdimensions, which

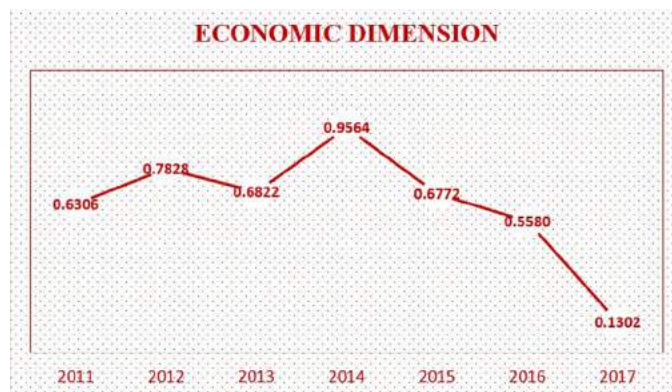

***Figure 2.** TOPSIS results of financial dimension*

TOPSIS: Technique for order preference by similarity to ideal solution

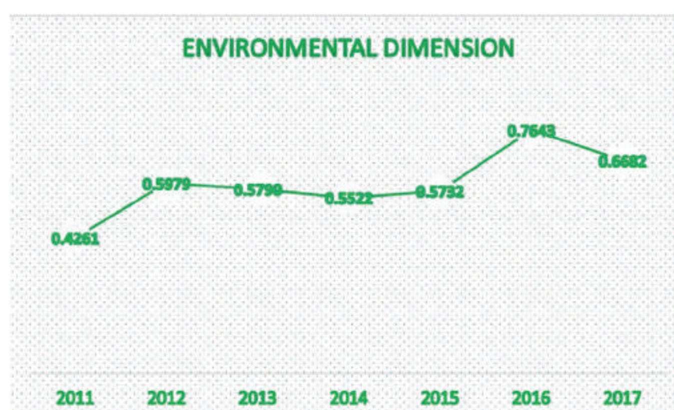

***Figure 3.** TOPSIS results of environmental dimension*

TOPSIS: Technique for order preference by similarity to ideal solution are considered under the environmental dimension of sustainability, will give positive results when they receive negative values. For example, GHG emission amount of a port is equal to 5,000 tons in one year and 3,000 tons in the next year. It is considered a positive directional change and a success, even though the mathematical value is decreased. Therefore, negative versions of all environmental dimension values obtained from the annual and sustainability reports of APM Terminals are used for calculation. As a result, the environmental sustainability performance of APM Terminals did not change much between 2012-2015 and continued to be stationary. Besides, the performance increases in 2012 and 2016 is considered to be remarkable.

While calculating the social dimension of sustainability in APM Terminals, two subdimensions value could not be reached in any reliable source published by APM Terminals. These are: 2011 values of the ratio of female employees in total employees and ratio of female employees work as a manager in total employees, and 2012 value of the ratio of female employees work as a manager in total employees. So these values filled up with the geometric means of the same values of other years. Also, due to the same reason that explained in the environmental dimension results of the study, the fatalities, lost-time injury, and sick leave accidents subdimensions values of social dimension were used with their negative versions. The result of social sustainability performance at APM Terminals is shown in Figure 4. The sharp decreases in 2014 and 2017 and the same increase in 2016 are considered remarkable.

Possible reasons for the performance of all dimensions of sustainability that increase and decrease will be analyzed in detail in the discussion of this study.

5. Discussion

In this part of the study, sustainability and annual reports of APM nalsrmi and sustainability and annual reports of APM Terminal related parts of Maersk Group between the years 2011 and 2017 reviewed again to gather the possible reasons for the sharp increase and decrease in the sustainability performance of APM Terminals.

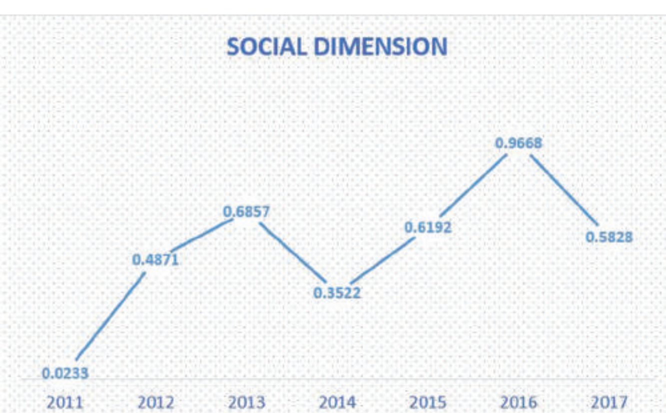

Figure 4. *TOPSIS results of social dimension*

TOPSIS: Technique for order preference by similarity to ideal solution

In 2011, APM Terminals defined their sustainability framework 12; the main objective that defined detailed as; “no harm to people, protect the environment, respect the neighbors, use energy and resources efficiently, lift global trade, publicly report the performance, promote best practices, manage health, safety, security, environmental and corporate responsibility (HSSE&CR) issues as critical business activity and promote a culture in which all employees share this commitment [36]”. In 2012, they had four core areas to reach sustainability, i.e., “health, safety and security, responsible business, environment and social responsibility [37]”. Zero significant spills for environment, 25% reduction in CO_2 emissions for climate change and increase diversity, and zero fatalities for the social dimension of sustainability were the 2013 goals of APM Terminals. The same year they also developed a materiality matrix that involved environmental and social issues of sustainability in gaining insight into which sustainability issues are especially important to their facilities [38]. Contrary to the opinion of Henri and Journeault [6], which was included in the literature section of this study that the social dimension of sustainability is generally neglected. This materiality matrix was considered important in terms of the importance that APM Terminals attach to the environmental and social dimensions of sustainability. In 2014, APM Terminals created an infographic highlighting some positive and negative impacts that their investments on the local area in terms of sustainability to minimize negative impacts and maximize positive impacts. With this system, they realized their negative impacts on ecology, traffic, land acquisition, etc. Their positive effect on wealth, employment, increased efficiency, reliability, etc.; this infographic worked like a roadmap for their sustainability practices [39].

5.1. Financial Dimension

In 2011, the increasing need for additional port capacity for the coming years had been forecasted by most industry experts, and APM Terminals already had long term growth prospects. That year it secured a few new investments in growth markets and took over operations in some regions, such as port of Callao, port of Peru, etc. During 2011, APM Terminals had 7 port projects in the development phase [36]. The expansion into a high growth market continued in 2012. Also, in 2012, APM Terminals launched a Global Transformation Project to increase operational performance, aiming to increase efficiency by 15% [40]. Even if Hurricane Sandy and some local political unrest or labor issues negatively affected the financial operations in some APM Terminals [40], it still achieved success in financial sustainability performance in 2012 (Figure 2). In 2013, two separate data were published by the port on their cash flow from operating activities that contradicted each other. According to the 2012 sustainability report, the cash flow from operating activities was given as 975 million USD; however, in 2013, the same was given as 910 million USD [37,38]. AHP results of this study gave this subdimension as the most important one; the author decided to use the 2012 data as the data provided in the 2012 report, as it will significantly impact the results. And this decrease (975 million USD to 923 million USD) in cash flow from operating activities, the most important subdimension, has emerged as the reason for the decrease in the financial sustainability performance of the port in 2013. However, 2014 was the most successful year for the APM Terminals in terms of financial sustainability. The success was mostly impacted by the sale of some APM Terminal facilities worldwide as that year, tax payments of the port increased significantly, and cash flow from operating activities was affected by it [41]. It is observed that the financial sustainability performance of the port has decreased continuously after 2014. Due to the global market conditions, the fall in oil prices in 2015 has had an unfavorable effect on several APM Terminals, especially those in oil-dependent markets. When added to these in the divestments of 2014, the year 2015 was not a very financially good year for APM Terminals [42]. In 2016, the port industry faced structural challenges due to larger container vessels and shipping lines consolidations and alliances. Hence, APM Terminals also faced these challenges in some of its important markets. As a result, its revenues and cash flows from operating activities decreased considerably [43]. Eight contracts of APM Terminals terminated in 2017 while they started 29 new contracts and faced various commercial challenges in that year. At the end, the operating profit of APM Terminals was reported as negative in 2017 due to the challenging market conditions and start-up costs of projects under implementation [44]. As a result, the financial sustainability performance of the port has reached rock bottom.

5.2. Environmental Dimension

APM Terminals achieved to save 1,652,715 liter of diesel fuel, reduce CO_2 emissions by 3,185 metric tons with the conversion of diesel-powered rubber tired gantry cranes to hybrid engines capable of using both diesel fuel and electricity in 2011 in some pilot areas. In addition to that, some APM Terminals in Europe have converted their power supplies to CO_2 neutral and wind generated electricity sources [36]. In 2012, APM Terminals identified three primarily important risk categories; "emissions to air, soil and water pollution and biodiversity" and they have committed themselves to reduce these risks in their terminals. Therefore, they contributed to developing some guidance prepared by the EU Ports European Group, UN Environment Programme, or World Conservation Monitoring Centre [37]. All these efforts to improve environmental sustainability performance were first observed in 2012 results (Figure 3) and led to improvement and development that will continue until 2016. In 2013, they focused especially on spills and emissions to air, and they developed a new reporting guidance for energy consumption, waste, water, and air emissions. In short, they determined the points on which they would focus in parallel with the results obtained from their materiality matrix in 2013. APM Terminals experienced small amounts of decrease in their environmental sustainability manners in 2014. When compared the 2013 their electricity consumption, energy consumption, GHG emissions, waste generations and water consumptions increased. Although these increases caused the small decrease that we saw in Figure 3, APM Terminals took action to prevent this from happening next year and identified 6 situations that needed urgent attention such as "emergency/spills response, management of chemicals and other dangerous substances, energy consumption and carbon emissions, water consumption, waste noise and light pollution (in locations in close proximity to local communities and/or biodiversity hotspots) [37]". The reports of 2015 do not contain very detailed information on efforts to improve environmental sustainability in APM Terminals. However, the world's first fully automated and emission-free, sustainable powered container terminal was launched in 2015 by APM Terminals [42]. Even though we do not encounter an unusual method to increasing environmental sustainability performance between 2013 and 2016. APM Terminals, which combined the reporting standard with the Maersk Group in 2016, made a radical change in their systems. Their materiality assessment matrix, first developed in 2012, updated and published since then. However, in 2016, the matrix was changed to a materiality model that provides better information about why and how an issue is material and how it can best be managed, as the matrix is about the expression of importance, not how to manage it. Their model consisted of three main materiality dimensions; responsibility, shared value, and risk [45]. With the transition from materiality matrix to materiality model, they reported the best environmental sustainability performances ever. Unfortunately, the sustainability report published in 2017 was an integrated report of APM Terminals and Maersk Group; thus, there is no clear information about APM Terminals environmental performance of that year. Hence it is not possible to explain the slight decrease demonstrated in Figure 3. But, according to the integrated report of oil spills and harmful releases of air (CO_2, NO_x, SO_x), it is demonstrated as a priority from the environmental perspective.

5.3. Social Dimension

In 2011, a safety leadership workshop was conducted as APM Terminals safety strategy, and four high risk areas were identified to develop an action plan. The same year, to improve safety and awareness of social sustainability issues via training and demonstrations of Global Safety Day celebrated in all APM Terminals [36]. In 2011 ten, and 2012 five fatal accidents occurred in various APM Terminals. Thus, in 2012 safety had become the first priority for APM Terminals. Four global safety commitment was created (safety is our license to operate, safety has no hierarchy, safety means no compromise, and safety is not optional) in 2012. A safety activist who has a strategic task about as defined by APM Terminals commented, "to influence the organization positively, find the weak spots, be the critical voice of conscience, facilitate debate and dialogue, challenge old ways of working and making the organization think and act differently [37]". As a result, all these precautions were expected to work as the number of fatal accidents in 2013 was reduced to three; that year was the second best year of the social sustainability performance of APM Terminals. Safety and zero fatality goal of APM Terminals continued to be the top priority in 2013; traffic, working at heights, falling objects, and stored energy defined as the main safety risks at the terminals. Necessary action plans were created to prevent accidents caused by these four risks and achieve the zero fatality target [38]. As shown in Figure 4, fatalities subdimension is the most important subdimension in social sustainability. Unfortunately, the year 2014 was the worst year of APM Terminals in fatalities with ten deadly accidents; thus, their social sustainability performance showed a sharp decrease. In 2014 they analyzed those fatal accidents, and they defined 5 fatal areas in the port, which are "transportation, suspended loads and lifting, working at heights, stored energy and contractor". When they defined these areas, they developed the "Fatal 5, a set of global operating standards," and made it mandatory to use all APM Terminal facilities [39]. This practice must have been successful as it seems that the number of fatal accidents has decreased considerably in the following years. In 2015, the port continued its "Fatal 5" campaign developed with new mitigating efforts such as; "standardized risk management principles, man and machine separation, performance criteria for equipment, new equipment, focusing on enhancing people capabilities and skills [42,46]". In 2016, fatality issues and safety were on the agenda again, and they continued to develop the "Fatal 5" program [45]. In addition to that transition from materiality matrix to materiality model, the best social sustainability performances have ever been achieved along with environmental performance. Safety continues to number one priority for APM Terminals in 2017 too. In some terminals, they started to use drones to some tasks such as looking at traffic flows, monitoring container stack efficiency or unsafe behavior, filming the site operations, etc. And they assessed the results as success and improvement of safety culture [47].

6. Conclusions

This work consisted of AHP and TOPSIS methods for a case company to detect the important degree of ports sustainability criteria, decide the port sustainability performance with the light of this important degree, and the possible reasons for port sustainability performance inequalities to all three dimensions of sustainability. Based on results, the importance regarding the degree of sustainability dimensions is determined as financial dimension, environmental dimension, and social dimension. Besides, the most important subdimension for each dimension is determined as operating profit for financial dimension, water consumption for environmental dimension, and fatalities for social dimension.

Financially, it has been observed that they have experienced a steady decline since 2014. And the financial improvement in 2014 was mostly impacted by the sale of some APM Terminal facilities. In 2017, the only negative operating profit value was reported over the years studied. After that, Maersk Group stopped publishing separate reports for APM Terminals and published them by combining the group reports; thus, it was not possible to observe the performance after 2017. Since APM Terminals serve simultaneously in many different regions of the world, it has become very sensitive to global risks and threats. Risks and threats arising from the falling in oil prices, and structural challenges due to larger container vessels, shipping lines consolidations, and alliances, have been felt more than others in certain regions of the world. However, for APM Terminals, it has been found that it negatively affects its entire performance.

When the environmental sustainability performance is analyzed by years, it has been determined that the graph tends to increase except for the years that can be considered as exceptions. Even if a slight decrease was observed in 2017, the value was higher than all other years except 2016, facing difficulty to evaluate that as a failure. The main reason behind the success of environmental sustainability performance is thought to be the system that was first developed as a materiality matrix in 2012 and upgraded as a materiality model in 2016. Because the materiality matrix, which began to be used in 2012, provided the highest performance ever, and the transition to the materiality model in 2016 has resulted in the highest performance to date.

When it comes to social sustainability performance, fatalities are the main subject of APM Terminals. Because of these deadly accidents, they reported their worst performance in 2014. In the same year, they identified 5 areas where fatal accidents were experienced intensely in the port as transportation, suspended loads and lifting, working at heights, stored energy, and contractor and developed a "Fatal 5" campaign. Within the scope of this program, they started to focus on training programs and in-port improvements. And even in the following years, they started working with drones in some pilot areas to find a solution to the problem of working in the heights. As a result, the number of fatal accidents has decreased considerably in the following years. In addition to the Fatal 5 program, the transition from materiality model that explained in environmental performance caused their best social sustainability performances ever due to the safety elements in the model.

Besides, while measuring the sustainability performance of the selected port, nine criteria suggested for port sustainability performance measurement in the literature have been used [17,23-25]. As a result of the study, it was determined that if the sustainability performance of the examined port was analyzed according to these criteria, significant increases and decreases in the sustainability performance could be observed. With this finding, the study in question supports the accuracy of the port sustainability measurement criteria suggested in the literature [17,23-25].

The APM Terminals, which were examined within the scope of the study, changed their reporting format after 2017 and started to publish data on all of the group companies, causing the study to be planned to cover only for seven years. Since sustainability performance is a phenomenon that is expected to improve over the years due to its nature, the most important limitation of the study is that the performance for post-2017 cannot be examined. Besides, there is no standard format for port sustainability report that allows all analyzes to be made exclusively for ports but does not allow performances of more than one port to be compared. In this context, it is recommended to develop a standard format for port sustainability reports for future studies. As a result of the study, it was concluded that systems such as the "Fatal 5 program" and "materiality model" developed and implemented by APM Terminals positively affect the sustainability performance of the ports. It is thought that conducting in-depth researches on these systems would contribute to the existing literature and benefit industry practitioners.

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Analysis of Draught Survey Errors by Extended Fuzzy Analytic Hierarchy Process

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Abstract

Bulk carriers and general cargo vessels have the largest number and tonnage among different types of ship fleets. According to the United Nations Conference on Trade and Development data in 2019, the tonnage of the global bulk carrier and general cargo vessel is 842,438,000 and 74,000,000 metric tons, respectively. The main cargo weight measurement method for bulk carriers and general cargo vessels is the draught survey calculation. In this study, a fuzzy analytic hierarchy process questionnaire was prepared based on previous studies and experts' opinions. Responses from the experts were consolidated to determine the priority vector of the criteria of draught survey error sources. Expert evaluations showed that the major reasons of draught survey inconsistencies are problems occurring at draught reading and ballast measurement stages. Accordingly, the most effective alternatives to minimize the errors were found to be training and documentation, which are closely related to education. This study aims to determine the draught survey error causes and their priorities along with different means to reduce the errors from the experts' opinions. This study will contribute to the literature by shedding light on draught survey errors in which studies in the academic literature are very limited.

Keywords

Bulk cargo, Draught survey, Fuzzy AHP

1. Introduction

A draught survey is based on Archimedes' principle and can be defined as a cargo calculation method, which is accepted in maritime transportation [1]. The main types of vessels for which a draught survey calculation is performed are bulk carriers [2]. However, a draught survey calculation is also used for all tankers in case of a difference between the vessel and shore figures or tank indicator failures and for stability calculations. According to United Nations Conference on Trade and Development, the major bulk commodities in 2018 are iron ore, grain, and coal, which in total corresponds to more than 40% of the total dry cargo shipments with 3.21 billion tons. Minor bulk and container shipments correspond to 25.8% and 24% of dry cargo shipments in the same year, respectively. The remaining part is covered by other dry cargo like break bulks [3].

Draught survey discrepancies can be avoided on a large scale if ideal conditions are provided before starting the survey. At any condition, the ship's trim should not exceed the existing value in trim correction tables of the tanks. The ship should be upright for minimizing the tank's sounding errors. All draught marks should be properly painted and visible [1]. During the survey, there should be no cargo, ballast, bunker, and crane or hatch cover operation. All equipment that will be used during the survey should be appropriately certified [2,4].

Draught surveys should be conducted before and after cargo operations, which are known as the initial and final draught surveys for the determination of cargo quantity handled. To perform a draught survey, the vessel

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draughts should be read very carefully by the shore and seaside of the vessel. This procedure is performed on the draught marks on the fore, aft, and amidships at both the port and starboard. If the draught marks are not on the perpendiculars, draught corrections for calculating the draught values on the perpendiculars should be carried out. Using the estimated mean draught, a draught survey is accomplished by determining the necessary values such as displacement, ton per centimeter, longitudinal center of flotation, and moment to change trim one centimeter provided in the stability booklet of the ship [4]. In a draught survey, the difference between the loaded net displacement and empty net displacement calculated at the ports of destination and departure provides the cargo quantity [5,6].

There are three elements of an unloaded vessel: lightship, constant, and variable weights (ballast, fuel, lube oil, fresh water, and store) of the vessel. Additionally, there is cargo on a loaded vessel [6]. The total of such weights determines the displacement of a vessel. Corrections and interpolations are required in numerous steps of a draught survey calculation, which increase the possibility of the introduction of an error. Moreover, the stakeholders feel compelled commercially to determine the amount of the merchandized load by a draught survey, and they might attempt to provide their own calculations in favor of their employers. Such factors increase the margin of error in a draught survey and have a negative impact on its reliability [7].

As a dry bulk cargo constitutes a significant majority of international trade, the method to be used for the quantification of such loads should yield the most correct value, possibly with a minimum margin of error. The electronic quality shipping information system (EQUASIS) is an online information system for making safety-related maritime information more accessible by gathering relevant data from maritime industry professionals like ship owners, insurers, brokers, classification societies, and ports. According to an assessment in 2011 of a merchant fleet based on EQUASIS data, the world merchant fleet was comprised of 79,074 ships, among which 26,631 ships were solid bulk cargo and general cargo carriers. This figure accounts for 33.7% of the total fleet, surpassing all other ship types in this regard [8]. In this case, a margin of error is used in methods for the quantification of dry bulk loads. Minimizing this margin of error would have a tremendous impact on world trade.

This study aims to obtain and prioritize the causes of draught survey errors and suggest the most effective alternatives for minimizing the errors from the perspective of the industry experts. Considering the mass of the cargo that is measured by draught survey, it is highly important to obtain the cargo quantity with the least error possible. The presented paper can be used as a framework for studies about the reduction of draught survey errors.

In this study, factors causing errors in a draught survey were analyzed based on the literature, and the hierarchical structure establishing the recommendations for reducing errors was assessed by the extended fuzzy analytic hierarchy process (FAHP) method.

2. Literature Review

A draught survey is a manual calculation method based on observation. As a consequence, compensations are claimed based on cargo shortages of the differences in draught surveys. This scenario remains the main source of concern for shipowners and insurance clubs [9]. Therefore, marine insurance clubs require studies to be conducted on the discrepancies in draught surveys [10]. Shipowners are accountable for third parties, the environment, crew, and the cargo on their vessels. Thus, the compensations for the damages arising from cargo shortages are generally covered by the Protection & Indemnity Club (P&I Club) insurance.

A bill of lading (B/L) of the transportation of cargo such as grains, coal, and mine, and the total load quantities discharged at the port of discharge are compared. Cargo shortage is claimed when the difference between these quantities is above the commercially acceptable limit (0.5%), which is highly common between the ports of discharge and loading [11]. This particularly occurs when cargos such as grains are measured based on the shore scale where the B/L document is issued according to the quantity measured onshore [12].

In a circular note published in 2016, the Japan P&I Club performed a statistical study on cargo shortages and presented assessments of reasons and actions to be adopted to prevent them. In the analyses, a total of 10,594 cargo-related damage events were detected between 2008 and 2014. Moreover, it was observed that 2,183 (21%) of these events were related to cargo shortages. In the same period, the payment made for cargo damages from the budget of the Japan P&I Club was USD 121 million in total. USD 22.8 million (i.e., 19%) of this payment was owed to cargo shortages [11].

Another study attempted to assess the potential errors in a draught survey using the AHP method [7], as it might afford solutions for multi-criteria complex problems. To attain the correct value in a draught survey, the factors considered as risks were assessed by pair-wise comparison. In the aforementioned study, the main criteria were reading the draughts, measuring the quantities of water in the vessel, measuring the density of seawater, and calculation stages. However, the study did not present alternatives for reducing errors. According to inferences by Xu et al. [7], the draught reading stage is the most significant stage of having a risk of error in a draught survey. Moreover, the most important factor among the sub-criteria in this stage is the surveyor. A surveyor should read the draughts carefully and objectively. Another important factor is the location where the draught survey is performed. The study stated that in recent years, reading draught (DR) marks using boats instead of ladders has considerably decreased disagreements and discrepancies in draught reading. It was also mentioned that the calculation should be performed during the measurement of the ballast quantity without ignoring the trim and list. Moreover, the survey should be initiated after the ideal surveying conditions are provided for the ship if its sounding table lacks the trim or list corrections. Xu et al. [7] mentioned the significance of using correct and licensed equipment for the measurement of seawater density and highlighted that using a computer-assisted calculation program might prevent calculation errors.

It is necessary to pursue maritime operations safely and efficiently for the purpose of maintaining global trade [13]. This necessity leads to scientific research and projects in the maritime sector concerning ship operations, autonomous technologies, electronic navigation, and VR education. Based on the literature, it is noted that the number of academic researches on draught survey is limited, and most of the information/data in company circulars, draught survey reports, and ship stability booklets have not been studied extensively based on experts' opinion by scientific perspective. These motivated this study's investigation on draught survey errors. This study obtains and quantifies draught survey error causes and suggests alternatives for the reduction of errors using the FAHP method based on experts' opinions. It is noted that presently, no article has analyzed draught survey errors and suggested alternatives from a scientific perspective in the literature. This study then fills this important gap in this field.

3. Analytical Hierarchy Process

The analytical hierarchy process (AHP) was first introduced by Myers and Alpert [14] in 1968 and was developed as a model by Saaty [15] in 1977, making it usable in solving decision-making problems. AHP can be explained as a decision-making and forecasting method that is used when a decision hierarchy can be defined, giving decision-making distributions. AHP is based on one-to-one comparisons on a decision hierarchy. As a result, their differences turn into percentages on their points. AHP is used in decision making in cases of certainty or uncertainty, multi-criteria, and multi-purpose, where many decision-makers can be found while choosing or ranking among many alternatives. AHP is a decision-making technique that measures all objective and subjective criteria by making a binary comparison and determines the order of importance by finding the priorities of these criteria relative to each other [16].

3.1. Fuzzy Analytic Hierarchy Process

The FAHP can be considered as an advanced analytical method that is used for modeling unstructured problems in several scientific fields, which is derived from Saaty's AHP method. The first study on FAHP was conducted by van Laarhoven and Pedrycz in 1983 [17]. Although AHP is consistent in considering both quantitative and qualitative criteria in multi-criteria decision-making problems, uncertain or fuzzy points in the determination of the decision-maker are demonstrated with the net numbers and fuzzy opinions of his/her being taken as to be certain in the assessment. As uncertain or fuzzy thoughts of the experts are part of the process, FAHP provides more realistic results than AHP [18]. Unclear and ambiguous points in AHP are improved using FAHP [19,20]. AHP is a multi-criterion method frequently used for solving problems [21]. However, it is criticized for using exact values in the assessment of experts' opinions and for its inability to appropriately consider uncertainties and negligence of pair comparisons [22]. By contrast, fuzziness, especially uncertainty, is significant in a decision-making problem. Specifically, if the problem to be solved is uncertain, this uncertainty should be tolerated by the problem-solving method [23]. The decision-making process requires making a decision based on relevant alternatives [24,25]. Some of the decision criteria may be in conflict throughout the process. Therefore, alternatives should be analyzed with a methodology that can assess all the criteria simultaneously during the process. In the AHP method, the opinions of the decision-makers are assessed; however, this assessment using exact values raises concerns [26].

3.2. Fuzzy Numbers

The concept of fuzzy logic entered the literature in 1965 with the publication of Zadeh's research articles on this subject. Fuzzy logic is defined as a mathematical order with strict rules for expressing and working with uncertainties [27]. Provisions involving people's preferences are often ambiguous. Since it is not possible to predict individual preferences with exact numerical values, modeling full numerical data in real life is insufficient. For modeling to show a realistic approach, the criteria used in the problems should be evaluated and weighted with linguistic variables [28].

A fuzzy number can be simply defined as the fuzzy subsets of a real set. It is more appropriate to express the opinions of experts using linguistic terms because it is a more realistic option compared to using exact numbers. Linguistic terms in Table 1 represent triangular fuzzy numbers defining the interval of the determinations, which are used in the calculations of FAHP [26]. Triangular membership functions, defined by an overlap of fuzzy controllers are often used in fuzzy models because of the simplicity of using membership functions and the use of very limited information when converting language terms into numerical data. The simplest process for converting a linguistic term as numerical data is a model that determines the lower and upper limits of the membership function. However, in this model, the distribution of membership degrees is linear among the specified limits. For the membership values to be appropriate at the selected intermediate points distributed within these specified limits, additional information (optimum value) about membership values is required. When the probabilities that give the optimal values of the criteria presented in the created fuzzy problem are specified, triangular membership functions with overlapping levels reduce the error value to zero [29]. In a classical set, an element either belongs to the set or not. Specifically, the result is 1 if the element belongs to the set and 0 if the element does not belong to it. In classical sets, there are no intermediate values. Unlike classical sets, fuzzy sets have intermediate values.

A triangular fuzzy number can be represented by (l/m, m/u) or (l, m, u) where l, m, and u correspond to the smallest possible value, the most possible value, and the largest possible value, respectively. If A is a triangular fuzzy number, the membership function can be defined as follows (formula 1) [26,29]:

$$\mu_{A(x)=}\begin{cases} 0, & x < l \\ \frac{x-l}{m-l}, & l \leq x \leq m \\ \frac{u-x}{u-m}, & m \leq x \leq u \\ 0, & x > u \end{cases} \qquad (1)$$

Figure 1 shows the membership function of fuzzy set A.

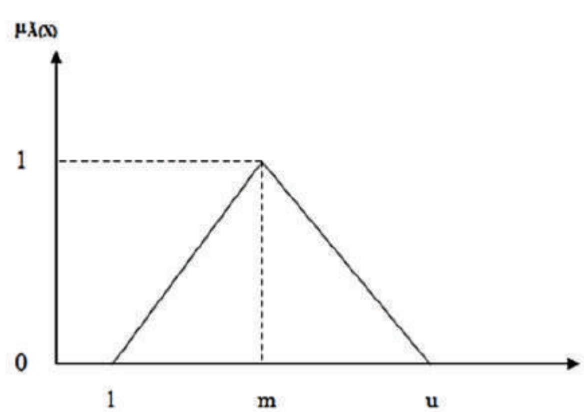

Figure 1. *Triangular membership function [28,30]*

3.3. Chang's Extent Analysis Method

Table 1. *Triangular fuzzy number values [20]*

Status	Triangular fuzzy numbers (TFN)	Reverse of TFN
Equally preferred	1. 1. 1	1. 1. 1
Moderately preferred	2/3. 1. 3/2	2/3. 1. 3/2
Strongly preferred	3/2. 2. 5/2	2/5. 1/2. 2/3
Very strongly preferred	5/2. 3. 7/2	2/7. 1/3. 2/5
Absolutely preferred	7/2. 4. 9/2	2/9. 1/4. 2/7

The extent analysis method developed by Chang (1996) has been used in numerous decision-making problems that employ FAHP [31]. Here, the significance levels of the necessary real numbers were calculated using a method based on Zadeh's extension principle [29,32]. According to the extended analysis, each alternative is assessed to achieve the goal of a criterion. The extent expression in the definition signifies the extent to which each object in the alternative section achieves the goals individually. The values of the extent analysis are triangular fuzzy numbers expressed as Mjg i (j=1, 2, ..., m; i=1, 2, ..., n) [33]. A one-to-one coverage analysis is performed with targets for each object, where $X=\{x_1, x_2, x_3, ..., x_n\}$ is the object set and $G=\{g_1, g_2, g_3, ..., g_n\}$ is the goal set. Coverage analysis values for each object are shown as follows (formula 2).

$$M_{gi}^{1}, M_{gi}^{2}, \ldots M_{gi}^{m}, i = 1,2,\ldots, M_{gi}^{j} \left(j = 1,2,\ldots m\right) \qquad (2)$$

Here, the parameters of $M_{gi}^{j}\left(j = 1, 2, \ldots, m\right)$ are triangular fuzzy numbers. a, b and c are the lowest possible, the highest possible, and the largest possible numbers, respectively.

A matrix is generated after the hierarchy is designed, and the opinions of the experts are obtained. Based on the generated matrix, the synthesis value (S_i) of the option is calculated by the following equation 3:

$$S_{i=} \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}, \qquad (3)$$

where (formula 4 and 5)

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \qquad (4)$$

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

The importance levels of the decision elements in the hierarchy are determined by comparing the calculated synthesis values. However, because the synthesis values are triangular fuzzy numbers, some points should be considered in the comparisons. When $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ are two triangular fuzzy numbers, the possibility degree of the $M_2 \geq M_1$ equation is expressed with the formula 6 below [34,35].

$$V(M_2 \geq M_1) = sup\left[\min\left(\mu_{M_1}(x), \mu_{M_2}(y)\right)\right], \left(y \geq x\right) \quad (6)$$

Sup in formula 5 means superiority value. The (x, y) pair x>y is indefinitely bounded to belong to M. If x is greater than y and limited to M, then the value of the vector will be the upper value of the minimum value between μ_{M_1} and μ_{M_2}. Equation (6) is a form of y ≥x inequality expressed according to the extension principle. The equation shows the greatness relationship between (x, y) numbers, which have a relationship such as y ≥ x and $\mu_{M1}(x)=\mu_{M2}(y)$. Specifically, it shows that the value demonstrating the possibility of M_2 being larger than M_1 is V ($M_2 \geq M_1$)=1. In this equation, if the median value of M_2 is larger than that of M_1, then the possibility of M_2 being larger than M_1 is 1. Otherwise, the probability can be estimated using Eq (7). However, calculating only the V ($M_2 \geq M_1$) value is not sufficient to compare two fuzzy numbers. The V ($M_1 \geq M_2$) value should also be calculated. With $M_1=(l_1, m_1, u_1)$ and $M_2=(l_2, m_2, u_2)$ as fuzzy numbers, the following equation will be used for calculating the V ($M_2 \geq M_1$) value (formula 7) [36]:

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

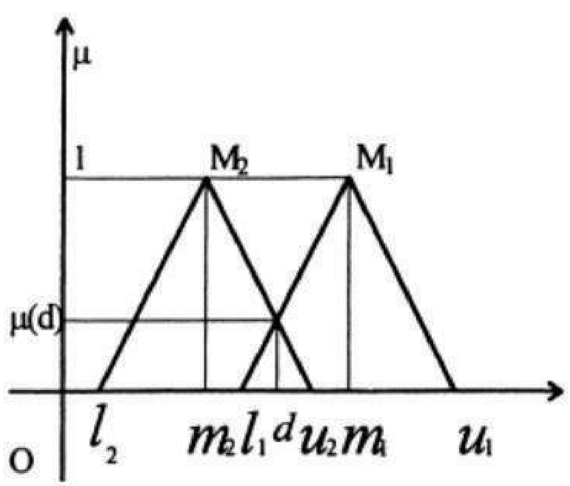

Figure 2. *Probability equation [20]*

After the pair-wise comparison, the lower values among the numbers obtained from the comparison of each criterion to the other two criteria are used in the calculation using the following equation 8:

$$V(M \geq M_1, \ldots M_n) = V[(M \geq M_1) \; and \; (M \geq M_2) \; and \ldots (M \geq M_n)] = \min V\,(M \geq M_i) \quad (8)$$

i=1, 2, 3, ..., m

∀k=1, 2, 3, ..., m

for $k \neq i$

3.4. Consistency Control for Pairwise Matrices

To calculate the consistency of the values obtained as a result of the application, the closest possible value of the fuzzy number was calculated using the dilution process proposed by Cheng et al. [37] in the paired comparison matrices. The rinsing process is calculated by the following equation 9.

$$M_d = \frac{(u - l) + (m - l)}{3} + l \quad (9)$$

Consistencies of the paired comparison matrices obtained as a result of the clarification processes were used in Saaty's [25] consistency rate calculation steps. The consistency ratio is calculated by the following equations 10-13.

$$E_i = \frac{d_i}{w_i} \quad (i = 1,2,\ldots,n) \quad (10)$$

$$\lambda = \frac{\sum_{i=1}^{n} E_i}{n} \quad (11)$$

$$CI = \frac{\lambda - n}{n - 1} \quad (12)$$

$$CR = \frac{CI}{RI} \quad (13)$$

The random index is shown in Table 2

Table 2. *Random index (RI) values*

N	RI	N	RI
1	0	7	1.32
2	0	8	1.41
3	0.58	9	1.45
4	0.90	10	1.49
5	1.12	11	1.51
6	1.24	12	1.48
Source: Saaty [25]			

4. Application of Fuzzy Extended Analytic Hierarchy Process

The transportation of dry bulk cargo is significant in world maritime shipping. Dry bulk shipment volume was 5.23 billion tons in 2018 and draught survey is the main method used to assess cargo quantity at dry bulks [3]. Cargo shortage is a common problem for these types of vessels. Hence, a review of the potential errors in a draught survey and the measures that can be adopted to reduce such errors are extremely important topics.

In this study, 100 draught survey reports of a particular voyage from 82 different ships were collected by authors who worked as marine surveyors or by requesting reports from companies conducting marine surveys. First, the differences in the draught survey quantities of the ports of loading and discharge were analyzed to find out whether there are remarkable differences between these figures. It was found that the draught survey quantity differences between loading and discharging ports were between 0.20-0.50% at 18 voyages and more than 0.50% at 9 voyages. The authors were then convinced that this issue should be investigated (Table 3).

In the second phase, the opinions of 7 experts with at least 6 years of bulk carrier experience onboard were obtained, and a decision hierarchy was constructed for the error sources and solution recommendations. Based on the decision hierarchy, a fuzzy AHP questionnaire was prepared by comparing the main criteria, sub-criteria, and alternatives for each set of criteria. In the third phase, the questionnaire was applied to a group of expert consisting of masters, officers, and draught surveyors (a total of 15 persons) with at least six years of experience onboard. The group comparison matrix was then created using the geometric mean (Table 4).

A total of 17 comparison matrices were generated, including comparisons of the main criteria, sub-criteria of each main criterion, and alternatives for each sub-criterion. Thus, priority degrees of the main criteria, sub-criteria, and alternatives were calculated using the fuzzy AHP methodology. According to the decision hierarchy formed (Figure 3), there are four main causes for the discrepancies in the draught survey. These errors at the time of draught reading are: errors at the time of ballast water measurement, errors related to the lack of training of the surveyor (LTS), and errors in the calculation step. The main criteria were divided into sub-criteria and the error causes were elaborated. In this study, the alternatives identified are training and documentation (TD), standardization in draught surveys (SDS), and control of the government agency (CG). After the application of the questionnaires and obtaining the final results from the experts' opinions, results were discussed with the experts who answered the questionnaires. Evaluation of the findings and conclusions with experts revealed that the results obtained from the study matches with those of the practice, indicating that our study is consistent.

Table 3. *Information about ships in which draught survey reports were collected*

Deadweight	Quantity	Cargo	Quantity	Draught survey differences	Quantity
1000-5000	5	Steel scrap	66	0-0.2%	73
5000-20000	21	Coal	6	0.2-0.5%	18
20000-50000	32	Grain	6	0.5-1%	4
More than 50000	42	Other bulk	22	More than 1%	5

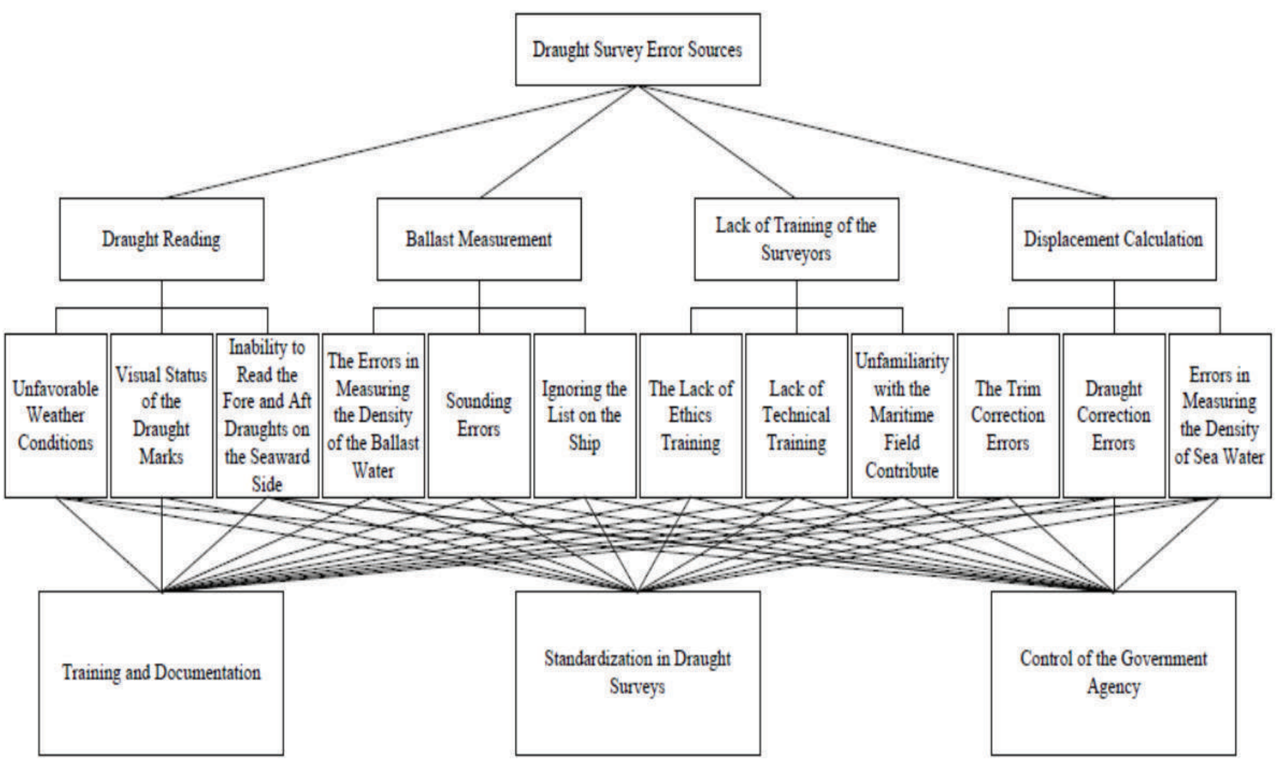

Figure 3. *Hierarchical structure of the study*

4.1. Criteria and Sub-criteria for Error Sources in Draught Survey

Criterion and sub-criterion effecting draught survey accuracy are obtained by referring to expert opinions. There are 4 main criteria and a total of 12 sub-criteria that consist the decision hierarchy as shown in Figure 3.

DR: This is a criterion involving the difficulties encountered at the time of draught reading and the errors that might potentially arise from these difficulties. The visual status of the draught marks (VSD), unfavorable weather conditions (WC), and in some cases, the reckoning of the fore, mean, and aft draughts on the seaward side (RDS) if they cannot be read are among the most common difficulties in draught reading [1,2,6,7].

Ballast measurement (BM): Measurement of the quantity of ballast water on a ship is a stage that might influence the consistency in a draught survey. The inability to measure the density of the ballast water (EDB), errors at the time of sounding the tanks (SE), and ignoring of the list on the ship (ILS) while estimating the volume of the ballast water as a sounding value are among the main error sources that can be potentially encountered in the measurement of the ballast water quantity [1,2,6,7].

LTS: The lack of knowledge of the surveyors in the draught survey stages and calculations (LTT), lack of familiarity with marine terms (UMF), not knowing the purpose and rationale of the processes in general, and failure to perform a correct and reasonable survey by considering the ethical values (LET) are the error sources that decrease the consistency and accuracy of the draught survey [11].

Displacement calculation (DC): The DC errors that can be made by the surveyors involved in a draught survey are the errors in trim corrections (TCE) and draught corrections (DCE) and can yield an incorrect density of the seawater (EDSW) [2,7].

Table 4. *Information about the experts who contributed to this study*

Expert profiles contributed to preparation of the decision hierarchy			
No	**Rank**	**Sea service (Years)**	**Draught surveyor experience (Years)**
1	Master	13	5
2	Master	10	3
3	Chief officer	6	2
4	Chief officer	7	5
5	Chief officer	7	3
6	Chief officer	8	4
7	Chief officer	6	8
Expert profiles rated the pairwise comparison matrix			
No	**Rank**	**Sea service (Years)**	**Draught surveyor experience (Years)**
8	Master	16	No
9	Master	14	No
10	Master	10	No
11	Master	9	1
12	Chief officer	7	6
13	Chief officer	6	2
14	Chief officer	8	1
15	Chief officer	8	1
16	Chief officer	6	4
17	Chief officer	9	No
18	Chief officer	6	1
19	Chief officer	8	No
20	Chief officer	6	3
21	Chief officer	6	2
22	Chief officer	7	1

4.2. Alternatives for Draught Survey Error Sources

Three alternatives have been obtained based on experts' opinions: TD, SDS, and CG.

TD: It is recommended that the draught surveyors receive a training whose curriculum is determined by relevant international institutions and that they perform their duties after receiving a certificate.

SDS: It is recommended that certain standards are set for the observation and equipment used in a draught survey.

CG: It is recommended that a completely impartial public officer, who has no commercial expectation or concern and is familiar with the draught survey rules and calculations, attends the draught survey with the surveyors who act in favor of the parties involved such as the buyer, seller, charterer, or shipowner.

5. Comparison Matrices and Priority Vectors

Based on expert assessment, 17 matrices were generated, which includes 1 matrix comparing the main criteria, 4 matrices comparing the sub-criteria, and 12 matrices comparing the alternatives for each sub-criterion.

The process of determining the priority vectors started after the matrices were generated. The priority vector of the main criteria was calculated using Table 5:

$W' = (1, 0.72, 0.49, 0.31)^T$.

The obtained values for the priority weights of the main criteria after normalization were as follows:

$W' = (0.40, 0.29, 0.19, 0.12)^T$.

According to the obtained data, draught reading, BM, LTS's, and DC have impacts, which are represented by the weights of 0.40, 0.29, 0.2, and 0.12, respectively, on the errors that occur in the draught survey.

Table 5. *Fuzzy pair-wise comparison matrix for the main criteria*

	DR	BM	LTS	DC
DR	(1.00-1.00-1.00)	(1.14-1.59-2.11)	(1.36-1.82-2.36)	(1.14-1.44-1.80)
BM	(0.47-0.63-0.87)	(1.00-1.00-1.00)	(0.87-1.26-1.78)	(1.14-1.59-2.11)
LTS	(0.42-0.55-0.74)	(0.56-0.79-1.14)	(1.00-1.00-1.00)	(0.87-1.26-1.78)
DC	(0.56-0.69-0.87)	(0.47-0.63-0.87)	(0.56-0.79-1.14)	(1.00-1.00-1.00)
				CR=0.059
DR: Reading draught, BM: Ballast measurement, LTS: Lack of training of the surveyor, DC: Displacement calculation				

The priority vectors of the sub-criteria of the main criterion draught readings were calculated using Table 6:

W_{DR}=(0.54, 0.23, 0.23)^T.

Based on the calculations, unfavorable WC, VSD, and the inability to read the fore and aft draughts on the seaward side have effects as represented by the weights of 0.54, 0.23, and 0.23, respectively, on the errors that occur during draught reading.

The priority vectors of the sub-criteria of the main criterion BM were calculated using Table 6:

W_{BM}=(0.29, 0.46, 0.25)^T.

According to the data obtained, the errors in measuring the EDB, sounding errors, and ILS have impacts as represented by the weights of 0.29, 0.46, and 0.25, respectively, on the errors that occur in the BM.

The priority vectors of the sub-criteria of the main criterion of the LTS were calculated using Table 6:

W_{LTS}=(0.38, 0.42, 0.2)^T.

The lack of ethics training, lack of technical training, and unfamiliarity with the maritime field contribute with the weights of 0.38, 0.42, and 0.2, respectively, to the errors due to the LTS.

The priority vectors of the sub-criteria of the main criterion of DC were calculated using Table 6:

W_{DC}=(0.34, 0.2 0.46)^T.

According to the data obtained, TCE, DCE, and errors in measuring the density of seawater have impacts with weights of 0.34, 0.2 and 0.46, respectively, on the errors that occur in the DC.

The priority vectors of the alternatives for the errors related to the draught reading were calculated for TD, standardization of draught surveys, and control of the government agency as follows using Table 7:

W_{WC}=(0.33, 0.65, 0.03)^T,

W_{VSD}=(0.19, 0.69, 0.03)^T,

W_{RDS}=(0.23, 0.72, 0.05)^T.

The priority vectors of the alternatives for errors related to the BM were calculated for TD, standardization of draught surveys, and control of the government agency as follows using Table 7:

W_{EDB}=(0.13, 0.13, 0.74)^T,

Table 6. *Fuzzy pair-wise comparison matrices for the sub-criterion of draught reading, ballast measurement, surveyor training, and displacement calculation criteria*

	WC	VSD	RDS
WC	(1.00-1.00-1.00)	(1.14-1.59-2.11)	(1.21-1.44-1.70)
VSD	(0.47-0.63-0.87)	(1.00-1.00-1.00)	(0.74-1.00-1.36)
RDS	(0.59-0.69-0.82)	(0.74-1.00-1.36)	(1.00-1.00-1.00)
			CR=0.064
	EDB	**SE**	**ILS**
EDB	(1.00-1.00-1.00)	(0.56-0.79-1.14)	(0.76-1.00-1.31)
SE	(0.87-1.26-1.78)	(1.00-1.00-1.00)	(1.14-1.59-2.11)
ILS	(0.76-1.00-1.31)	(0.47-0.63-0.87)	(1.00-1.00-1.00)
			CR=0.081
	LET	**LTT**	**UMF**
LET	(1.00-1.00-1.00)	(0.56-0.79-1.14)	(1.14-1.59-2.11)
LTT	(0.87-1.26-1.78)	(1.00-1.00-1.00)	(1.04-1.44-1.99)
UMF	(0.47-0.63-0.87)	(0.50-0.69-0.97)	(1.00-1.00-1.00)
			CR=0.048
	TCE	**DCE**	**EDSW**
TCE	(1.00-1.00-1.00)	(1.14-1.26-1.36)	(0.56-0.79-1.14)
DCE	(0.74-0.79-0.87)	(1.00-1.00-1.00)	(0.50-0.69-0.97)
EDSW	(0.87-1.26-1.78)	(1.04-1.44-1.99)	(1.00-1.00-1.00)
			CR=0.031
WC: Weather conditions, VSD: The visual status of the draught marks, RDS: The reckoning of the fore, mean, and aft draughts on the seaward, ILS: Ignoring of the list on the ship side, TCE: The errors in trim corrections, DCE: Draught corrections, EDB: Errors in measuring the density of the ballast water, SE: Sounding errors, LET: Lack of ethical training, LTT: Lack of technical training, UMF: Unfamiliarity with the maritime field, EDSW: Errors in measuring the density of sea water			

W_{SE}=(0.53, 0.06, 0.41)^T,

W_{ILS}=(0.46, 0.2, 0.34)^T.

The priority vectors of the alternatives for the errors related to the LTS were calculated for TD, standardization of draught surveys, and control of the government agency as follows using Table 7:

W_{LET}=(0.62, 0.06, 0.31)^T,

W_{LTT}=(0.93, 0.07, 00)^T,

W_{UMF}=(0.89, 0, 0.11)^T.

Table 7. *Fuzzy pair-wise comparison matrix for the alternatives with respect to draught reading, ballast measurement, surveyor training, and displacement calculation criteria*

	TD	SDS	CG
Draught reading criterion			
Comparison of alternatives of sub-criterion EDB			
TD	(1.00-1.00-1.00)	(0.87-1.00-1.14)	(0.74-0.79-0.87)
SDS	(0.87-1.00-1.14)	(1.00-1.00-1.00)	(0.74-0.79-0.87)
CG	(1.14-1.26-1.36)	(1.14-1.26-1.36)	(1.00-1.00-1.00)
			CR=0.032
Comparison of alternatives of sub-criterion SE			
TD	(1.00-1.00-1.00)	(1.52-1.59-1.65)	(0.87-1.26-1.78)
SDS	(0.61-0.63-0.66)	(1.00-1.00-1.00)	(0.50-0.69-0.97)
CG	(0.56-0.79-1.14)	(1.04-1.44-1.99)	(1.00-1.00-1.00)
			CR=0.004
Comparison of alternatives of sub-criterion ILS			
TD	(1.00-1.00-1.00)	(1.04-1.44-1.99)	(0.87-1.26-1.78)
SDS	(0.50-0.69-0.97)	(1.00-1.00-1.00)	(0.74-0.79-0.87)
CG	(0.56-0.79-1.14)	(1.14-1.26-1.36)	(1.00-1.00-1.00)
			CR=0.031
Ballast measurement criterion			
	TD	**SDS**	**CG**
Comparison of alternatives of sub-criterion WC			
TD	(1.00-1.00-1.00)	(0.56-0.79-1.14)	(1.14-1.26-1.36)
SDS	(0.87-1.26-1.78)	(1.00-1.00-1.00)	(1.52-2.00-2.56)
CG	(0.74-1.26-1.78)	(0.39-0.50-0.66)	(1.00-1.00-1.00)
			CR=0.029
Comparison of alternatives of sub-criterion VSD			
TD	(1.00-1.00-1.00)	(0.42-0.55-0.74)	(1.00-1.14-1.33)
SDS	(1.36-1.82-2.36)	(1.00-1.00-1.00)	(1.16-1.59-2.16)
CG	(0.75-0.87-1.00)	(0.46-0.63-0.86)	(1.00-1.00-1.00)
			CR=0.031
Comparison of alternatives of sub-criterion RDS			
TD	(1.00-1.00-1.00)	(0.42-0.55-0.74)	(1.00-1.26-1.55)
SDS	(1.36-1.82-2.36)	(1.00-1.00-1.00)	(1.36-1.82-2.36)
CG	(0.64-0.79-1.00)	(0.42-0.55-0.74)	(1.00-1.00-1.00)
			CR=0.031
Surveyor training criterion			
	TD	**SDS**	**CG**
Comparison of alternatives of sub-criterion LET			
TD	(1.00-1.00-1.00)	(1.16-1.59-2.16)	(1.14-1.59-2.11)
SDS	(0.46-0.63-0.86)	(1.00-1.00-1.00)	(0.66-0.69-0.74)
CG	(0.47-0.63-0.87)	(1.36-1.44-1.52)	(1.00-1.00-1.00)
			CR=0.031
Comparison of alternatives of sub-criterion LTT			
TD	(1.00-1.00-1.00)	(1.78-2.29-2.80)	(1.78-2.29-2.80)
SDS	(0.36-0.44-0.56)	(1.00-1.00-1.00)	(0.87-1.26-1.78)
CG	(0.36-0.44-0.56)	(0.56-079-1.14)	(1.00-1.00-1.00)
			CR=0.033

Table 7. *Continued*

Surveyor training criterion			
	TD	**SDS**	**CG**
Comparison of alternatives of sub-criterion UMF			
TD	(1.00-1.00-1.00)	(1.04-1.44-1.99)	(0.87-1.26-1.78)
SDS	(0.50-0.69-0.97)	(1.00-1.00-1.00)	(1.00-1.00-1.00)
CG	(0.56-0.79-1.14)	(1.00-1.00-1.00)	(1.00-1.00-1.00)
			CR=0.031
Displacement calculation			
	TD	**SDS**	**CG**
Comparison of alternatives of sub-criterion TCE			
TD	(1.00-1.00-1.00)	(1.99-2.52-3.04)	(1.14-1.59-2.11)
SDS	(0.33-0.40-0.50)	(1.00-1.00-1.00)	(0.66-0.69-0.74)
CG	(0.47-0.63-0.87)	(1.36-1.44-1.52)	(1.00-1.00-1.00)
			CR=0.018
Comparison of alternatives of sub-criterion DCE			
TD	(1.00-1.00-1.00)	(1.99-2.52-3.04)	(1.14-1.59-2.11)
SDS	(0.33-0.40-0.50)	(1.00-1.00-1.00)	(0.66-0.69-0.74)
CG	(0.47-0.63-0.87)	(1.36-1.44-1.52)	(1.00-1.00-1.00)
			CR= 0.018
Comparison of alternatives of sub-criterion EDSW			
TD	(1.00-1.00-1.00)	(0.87-1.00-1.14)	(0.87-1.00-1.14)
SDS	(0.87-1.00-1.14)	(1.00-1.00-1.00)	(0.74-0.79-0.87)
CG	(0.87-1.00-1.14)	(1.14-1.26-1.36)	(1.00-1.00-1.00)
			CR= 0.075

TD: Training and documentation, SDS: Standardization in draught surveys, CG: Control of the government agency, ILS: Ignoring of the list on the ship side, WC: Weather conditions, VSD: The visual status of the draught marks, RDS: The reckoning of the fore, mean, and aft draughts on the seaward, EDB: Errors in measuring the density of the ballast water, SE: Sounding errors, LET: Lack of ethical training, LTT: Lack of technical training, UMF: Unfamiliarity with the maritime field, EDSW: Errors in measuring the density of sea water, TCE: The errors in trim corrections, DCE: Draught corrections

The priority vectors of the alternatives for the errors related to the DC were calculated for TD, standardization of draught surveys, and control of the government agency as follows using Table 7:

W_{TCE}=(0.89, 0, 0.11)^T,

W_{DCE}=(0.89, 0, 0.11)^T,

W_{EDSW}=(0.33, 0.22, 0.44)^T.

After the weight vectors of all the main criteria, sub-criteria, and alternatives for the criteria were obtained, the overall priority vectors of the alternatives were calculated. In this step, based on the sub-criteria, the priority vectors of the main criteria of the alternatives were calculated by multiplying the priority vectors of the sub-criteria by those of the alternatives (Table 8).

After the weights of the alternatives were determined by the main criteria, those based on the goal were calculated as shown in Table 9 following the directions in Table 8.

Based on the calculation, to solve the problem of the error sources in the draught survey, TD alternative has a prioritized significance with a priority weight of 0.44. Standardization in the draught survey (0.33) and control of the government agency (0.23) are identified as the best alternatives for problem solving.

6. Discussion

Our study reveals that the errors occurring in the draught reading stage are the main source of draught survey errors with 0.40 priority weight. It is followed by BM (0.29), lack of training (0.19), and DC errors (0.12) by weight vector order. Two major factors with priority weights of 0.40 and 0.29 have a big impact on draught survey errors. This means that corrective actions for these factors will have a great impact on the reliability of draught surveys.

In parallel with a previous study conducted by Xu et al. [7], the draught reading stage is found to be the main source of draught survey errors. However, the priority weight of the draught reading stage in our study is found to be lower compared to the aforementioned study.

Similar to the Japan P&I Club loss prevention bulletin

Table 8. *Weight factors of the alternatives determined by the main criteria*

Priority vectors for the main criterion of reading draughts				
	WC	**VSD**	**RDS**	**Priority vector**
Importance level	0.22	0.09	0.09	
TD	0.33*0.22	0.19*0.09	0.23*0.09	0.11
SDS	0.65*0.22	0.69*0.09	0.72*0.09	0.27
CG	0.03*0.22	0.12*0.09	0.05*0.09	0.02
Priority vectors for the main criterion of ballast measurement				
	EDB	**SE**	**ILS**	**Priority vector**
Importance level	0.08	0.13	0.07	
TD	0.13*0.08	0.53*0.13	0.46*0.07	0.11
SDS	0.13*0.08	0.06*0.13	0.20*0.07	0.03
CG	0.74*0.08	0.41*0.13	0.34*0.07	0.14
Priority vectors for the main criterion of lack of training of surveyors				
	LET	**LTT**	**UMF**	**Priority vector**
Importance level	0.07	0.08	0.04	
TD	0.62*0.07	0.93*0.08	0.49*0.04	0.14
SDS	0.06*0.07	0.07*0.08	0.24*0.04	0.02
CG	0.31*0.07	0*0.08	0.27*0.04	0.03
Priority vectors for the main criterion of displacement calculation				
	TCE	**DCE**	**EDSW**	**Priority vector**
Importance level	0.04	0.02	0.06	
TD	0.89*0.04	0.89*0.02	0.33*0.06	0.08
SDS	0*0.04	0*0.02	0.22*0.06	0.01
CG	0.11*0.04	0.11*0.02	0.44*0.06	0.03

TD: Training and documentation, SDS: Standardization in draught surveys, CG: Control of the government agency, WC: Weather conditions, VSD: The visual status of the draught marks, RDS: The reckoning of the fore, mean, and aft draughts on the seaward, EDB: Errors in measuring the density of the ballast water, SE: Sounding errors, LET: Lack of ethical training, LTT: Lack of technical training, UMF: Unfamiliarity with the maritime field, EDSW: Errors in measuring the density of sea water, TCE: The errors in trim corrections, DCE: Draught corrections

Table 9. *Weight factors of the alternatives determined by the goal*

	DR	**BM**	**LTS**	**DC**	**Total weights**
TD	0.11	0.11	0.14	0.08	0.44
SDS	0.27	0.03	0.02	0.01	0.33
CG	0.02	0.14	0.03	0.03	0.23

TD: Training and documentation, SDS: Standardization in draught surveys, CG: Control of the government agency, DR: Reading draught, BM: Ballast measurement, LTS: Lack of training of the surveyor, DC: Displacement calculation

[11], it is denoted that different surveyors may interpret readings and calculations differently, which may bring out big variations in final results.

In similar to the UK P&I Club 2008 draught survey bulletin [2], our study shows that the measurement of ballast water quantity is a considerable source of errors that may end up with unacceptable inaccuracies. Additionally, in the same bulletin, it is recommended that draughts should be read from both sides of the vessel. As mentioned in the bulletin, it is a fact that reading the offside draught marks onto a service boat will provide a more stable and reliable draught reading. This is in parallel with our findings.

In parallel to our study, Isbester [6] indicates that rough sea conditions will make accurate draught reading difficult or impossible to obtain. Our study reveals that an inaccuracy in the draught reading stage has the greatest effect on draught survey errors and the main source of draught reading errors is rough seas. Isbester [6] also points out that the wrong measurement of seawater or ballast water density may cause remarkable errors in draught surveys. These issues are also evaluated in our study and errors during the measurement of both ballast water density and seawater density, which were found to affect the accuracy of draught surveys.

ECE [1] indicates that careless repainting of draught marks can cause an erroneous reading. This error source is related to the VSD that is evaluated as a cause of inaccuracy at the draught reading stage in our research, showing similar indications between the two papers.

In our study, unlike the previous research conducted by Xu et al. [7], the education effect on draught survey errors is ranked A. The "LTS" criterion is found to be the third main source of draught survey errors with 0.2 priority weight. Ethical and technical problems occurring due to surveyors are commonly mentioned factors affecting draught survey accuracy in the literature. However, quantifying their effects on the draught survey accuracy was a gap that is answered by our study from the experts' perspectives.

Contrary to previous studies, alternatives for improving draught survey reliability are suggested. Effects of suggested alternatives are analyzed using the fuzzy AHP method and the priority weights of the alternatives are quantified. The proposed prioritized alternatives can be a guide for minimizing draught survey errors, as they include the potential contribution that each alternative can offer to the improvement of the problem.

Limitations of the study: Officers and masters contributed to our study by their opinions based on their work experience in ships with a deadweight between 3,000-82,000 MT. Draught surveyors with sea service experience contributed to our study by their opinions based on working as surveyors in Turkish Ports only.

7. Conclusions

Considering the alternatives suggested, it is concluded that corrective actions against human errors will decrease existing errors and increase draught survey reliability. A well-planned training program giving both ethical and technical education and competency to the surveyors is the main solution for this issue. The surveyors who receive draught survey training should be awarded a card serving as a certificate of authorization, and those who do not hold a certificate of competency should be prevented from participating in draught surveys.

Preparing a standard draught survey program for vessels and surveyors and performing draught survey calculations in such programs to prevent operational errors would improve the accuracy of the calculation.

Warnings such as fines or suspended entry to ports for a specific duration should be imposed on the surveyors or crew members who act in a misleading manner or repeatedly make incorrect calculations. Because there is no penal sanction on the surveyors or crew members who act in a misleading manner, setting standards in this regard would have an impact in dissuading such behaviors.

For ignoring malicious manipulations from surveyors working on behalf of different parties, stevedores and other participants to draught surveys, a public officer who has no commercial relationship with any of the parties at the ports and who cannot be pressured might be assigned to control the readiness and compliance of the conditions and parties to the survey by accompanying the survey step and also for performing the draught survey calculation for official records. Every surveyor should have their own equipment that will be used during the survey and their certificates should be checked by all surveyors. Any surveyor with invalid equipment or certificate should not be allowed to participate in the draught survey.

Standards should be set for the WC required for a draught survey. DR of seaside marks on a boat should be set compulsory for both the safety and accuracy of the survey. In case the cargo quantity is assessed by a shore scale, the responsible party should also send a surveyor for the draught survey to check the cargo quantity. Else, it should be accepted by the rules that the ship has no responsibility on the cargo quantity at any port related to that particular voyage to ignore malicious stevedore manipulations.

As researches about draught survey errors and their sources are very limited in the academic literature, the authors of this study believe that it is necessary to focus on this issue and enlighten the dark spots. In this research, draught survey errors were analyzed by the fuzzy AHP method that is based on experts' opinions. For this reason, the study's determinations of draught survey error sources are limited with experts' opinions and perspectives. It is recommended to research on the P&I official cargo shortage case reports (where cargo quantity is assessed by draught survey) to determine human and technical factors in draught survey errors for a more comprehensive content.

Authorship Contributions

Concept design: R. Canımoğlu, U. Yıldırım, Data Collection or Processing: R. Canımoğlu, Analysis or Interpretation: R. Canımoğlu, U. Yıldırım, G. M. İnegöl, Literature Review: R. Canımoğlu, U. Yıldırım, G. M. İnegöl, Writing, Reviewing and Editing R. Canımoğlu, U. Yıldırım, G. M. İnegöl.

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