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

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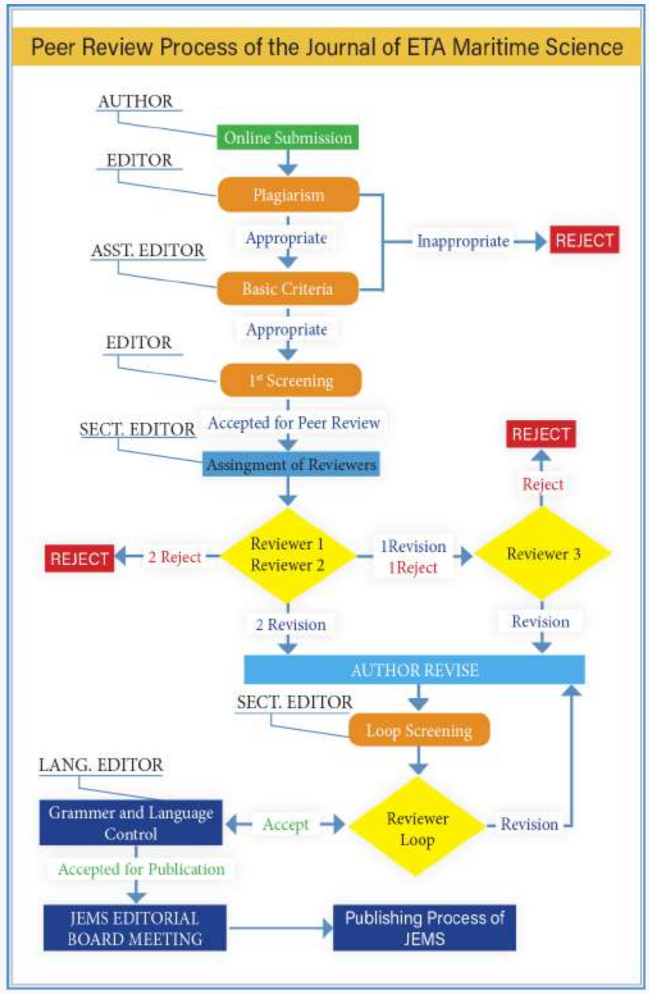

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Guide for Authors

Abstract

This sample includes the manuscript preparation guideline of Journal of ETA Maritime Science (JEMS). In the abstract section, a brief indicating the novelty and main findings of the study should be written. The text of the 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 considerable numbers of understandings in the maritime sector. Besides, JEMS also aims to reach out to relevant audiences by publishing the 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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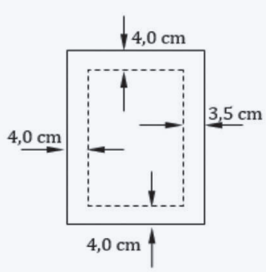

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The use of tables and figures should be kept to a **minimum**. For readability purposes, the total number of tables and figures should be no more than **10** per article.

1 OrcaFlex Program

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The table heading should be placed above the table. The figure heading should be placed below the figure. **2 nk** spaces should be added **before** the table heading and figure heading, and also **3 nk** spaces should be added next. The "table" and the "figure" should be written in bold and left-aligned. The first letters of the table, figure and equation headings should be written with capital letters. The heading and the content should be written with **"Cambria"** font and **10-point size**. Suppose tables, figures and equations in the study are cited. In that case, their references should be stated. **2 nk spaces** should be added **before** references, and **3 nk spaces** should be added **after**. If tables and figures don't fit into a single column, they should be designed to include two columns. Tables and figures which include two columns should be stated at the top or bottom of the page.

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. The journal administration will make these adjustments.

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 short research using structured interview methods with a veteran, recognized with knowledge and expertise in a specific subject, to seek his/her advice in a predetermined topic concerning the maritime industry (Organized by the editor). Title, Author, Abstract, Short biography of the interviewee, Methodology, Questions and Comments, Results, Interview Permit Certificate (Maximum 3000 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 maritime science, guide young academicians and researchers, and offer solutions for the demands of the maritime industry. (Invited by the editor).

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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 as 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 to convey the impressions, congress conclusion reports, and information gathered during scientific conventions following a congress, conference, and symposium organized on such matters concerning the maritime industry. (Maximum 500 words).

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Contents

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Journal of ETA Maritime Science 2022;10(1):1

Selçuk Nas

Dokuz Eylül University Maritime Faculty, Department of Maritime Education and Training, İzmir, Turkey

Dear Readers,

We are pleased to introduce JEMS 10 (1) to our valuable followers. There are valuable and intriguing studies in this issue of the journal. We hope that these studies will contribute to the maritime industry. Hereby, I would like to express our gratitude to the authors, who sent their valuable studies for publication in this issue, our reviewers, editorial board, section editors, and the publisher, who provided quality publications by diligently following our publication policies.

Yours Sincerely,

Prof. Dr. Selçuk NAS
Editor in Chief

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Journal of ETA Maritime Science 2022;10(1):2-15

A Fuzzy-Bayesian Approach on the Bankruptcy of Hanjin Shipping

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Abstract

The vital role of container liner shipping in international trade suggests that understanding why container liner firms go bankrupt is crucial to the sustainability of the maritime supply chain to improve resilience. Considering the insolvency of Hanjin Shipping as a case study, this paper investigates the probabilistic relationships among the bankruptcy causal factors that are disclosed qualitatively and quantitatively, exploiting a fuzzy Bayes network approach. A sensitivity analysis is conducted to increase the accuracy of the findings. Outcomes of the paper reveal that an integrated approach comprising of both endogenous and exogenous causal factors is a more powerful approach to explain the demise of Hanjin Shipping. Compared to exogenous factors, endogenous factors account more for the collapse of the firm. Furthermore, it is found that government support would have been a more influential measure to mitigate the negative effects of the demise compared to the merging and acquisition practice. Competitor liner operators, policymakers, and stakeholders in the maritime supply chain ecosystem can utilize the outcomes of this research to mitigate the bankruptcy risk and improve the maritime supply chain resilience capacity.

Keywords: Bankruptcy, Causal factors, Liner industry, Hanjin Shipping, Fuzzy Bayes network

1. Introduction

There has been a significant increase in global trade, particularly in maritime transportation in the last 30 years [1]. The shipping trade volume increased from 4 billion tons in 1990 to 10.65 billion tons in 2020. A significant part of this trade is carried by container shipping with the volume reaching 152 million twenty-foot equivalent unit (TEU) in 2018 [2,3]. As a dynamic industry, the container shipping industry acts as a key artery of the global economy. However, the weakening global economic outlook harms the operating cash flow of container shipping companies and undermines their balance sheets. Due to the economic impact of the financial recession in 2008, container shipping firms have gone through a cycle of financial challenges with many container liner firms having filed for insolvency [4]. Under this atmosphere, Hanjin Shipping filed bankruptcy protection on August 31, 2016 and was declared bankrupt in February 2017 [5]. The bankruptcy of Hanjin Shipping was the largest the industry has ever witnessed [6], which has worried so many container lines. Given the scope of this container shipping giant's bankruptcy, studies regarding this catastrophic event remain quite a few. The crucial role that container liner shipping plays in international trade suggests that understanding why container ship operators go bankrupt is of vital importance to the stability and sustainability of container liner shipping.

Considering previous studies, a dramatic rise has been observed in the domain of bankruptcy studies, especially since the 2008 financial recession. These studies fundamentally fall within two areas: (1) bankruptcy prediction and (2) business failure processes [7-10]. Similarly, Amankwah-Amoah et al. [11] point out that the last two decades can be regarded as a golden age of bankruptcy studies with a burgeoning research body that considers bankruptcy causes. Some studies in the literature disclosed the causes of dissolved firms. However, despite a burgeoning research body concerning bankruptcy causes, the majority of the studies that have been conducted

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in the maritime transportation domain fall within the scope of bankruptcy prediction [12-15]. Few studies have been carried out that concerns bankruptcy causes, which investigate the bankruptcy of Hanjin Shipping qualitatively. In this context, Pauli and Wolf [16] identified the underlying causes for the liquidation of Hanjin Shipping and analyzed the impact of its bankruptcy from different perspectives such as the South Korean economy, global container liner industry, and actors in Hanjin's immediate proximity. Similarly, Dong-Wook et al. [17] qualitatively revealed the causes that account for why the Hanjin liner firm collapse, and Shin et al. [18] provided bankruptcy reasons briefly, particularly about failed chartering practices. In addition, Li and Dong [4] attempt an analysis on whether China ought to adopt the UNCITRAL Model Law on Cross-Border Insolvency utilizing a strategic game theory approach by taking the Hanjin case into account. A common point in these studies is the qualitative approach of the bankruptcy of the Hanjin firm by solely revealing the failure causes. However, as to the authors' knowledge, no study in the literature has tested the bankruptcy contributory causal factors of a container shipping firm empirically. To evaluate the organization's weak areas and implement mitigating strategies to avoid bankruptcy, it is vital to have an understanding of the amount to which each causal element plays a part in the failure of a container shipping company. Therefore, utilizing these papers [16-18] in terms of failure causes and taking the bankruptcy of the Hanjin firm into account, this paper is a preliminary research that investigates the causal mechanism of a container shipping firm both qualitatively and quantitatively. Further, this paper is an initial research that tests the contributory causal factors for the container shipping firm empirically. Utilizing the Bayesian inference under a fuzzy environment, this paper presents and reveals the probabilistic relationships among the causal factors that led to the bankruptcy of Hanjin Shipping. Results of this research support the body of the literature suggesting that an integrated approach is more powerful to explain the failure causal mechanism than endogenous and exogenous do solely. It is also found that endogenous factors have a more impact in explaining the failure phenomenon than exogenous factors. This study is structured as follows. After introducing the topic, the stages of the Fuzzy-Bayesian approach are explained in section 2. The application of the chosen method, establishment/definitions of variables, and sensitivity analysis are provided in section 3. Results of the established model are discussed and some suggestions were made for the formulation of managerial policies in section 4. Finally, the outcomes are summarized in section 5.

2. Methodology

This section provides the details of the Fuzzy-Bayesian network (FBN) approach with the conceptual framework of the methodology shown in Figure 1.

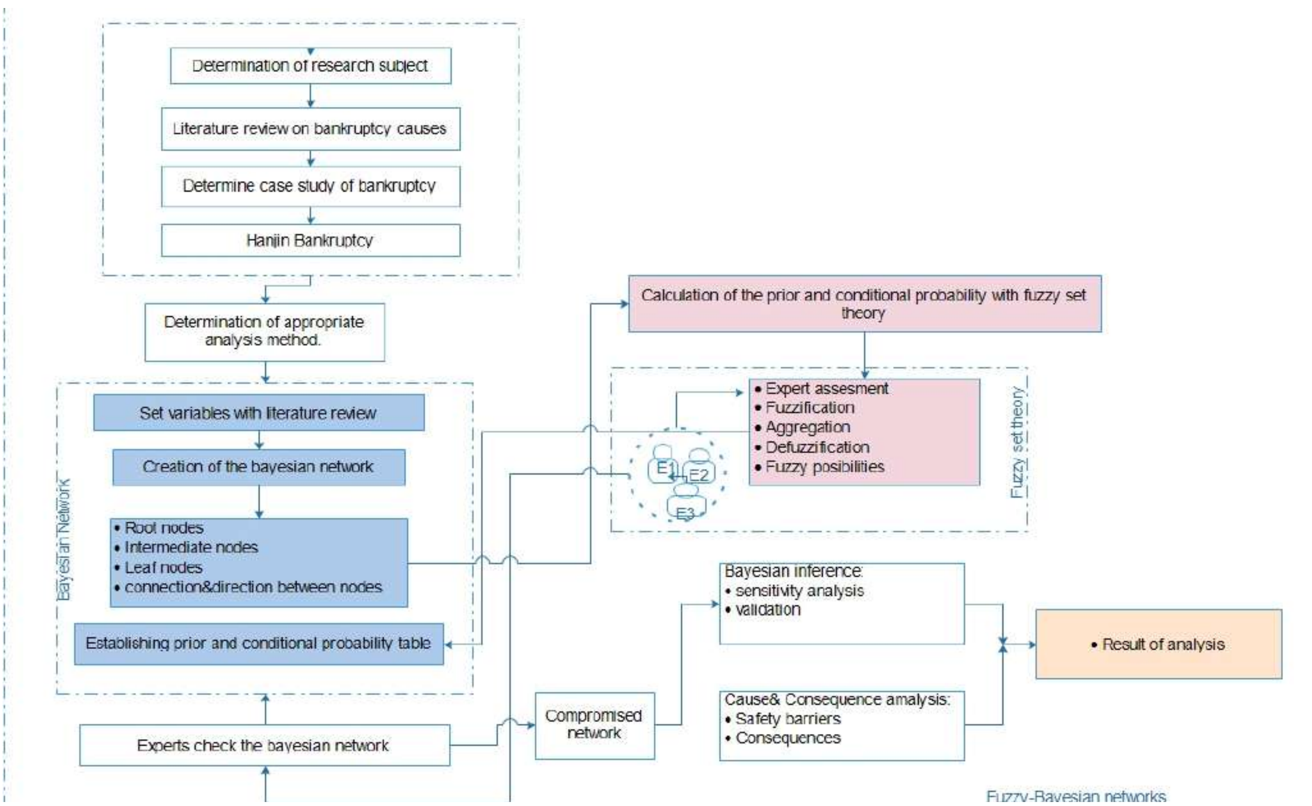

Figure 1. *Research flow chart*

2.1. Bayesian Networks (The BN)

The Bayesian Network (BN) approach is gaining increased popularity in the modeling of complex problems that involve probabilistic reasoning. This approach is employed in many different areas including bankruptcy studies [19]. The BN is a flexible and powerful graphical model that discloses the probabilistic relationships between variables [20-22].

The BN approach is also called directed acyclic graph since the relationships between variables are demonstrated on directed acrylic arrows. The graphical representation of the network comprises nodes that display variables, and the directed arrows show the probabilistic causal dependence among the variables. In this illustration, a node in which an arrow originates is called a parent node, while the node to which the arrows are directed is named a child node [23,24].

The quantitative component of the BN manages the probability tables of the variables in the network structure. Probability tables incorporate probabilities, conditional probabilities, and posterior probabilities that are extracted from them. A probability that belongs to the root node is named a marginal probability. Theoretically, the conditional probability table (CPT) and the marginal probability of root nodes could be formulated by incorporating statistical data, expert experience, or a combination of both [25]. The inference principle of the BN approach is based on the Bayes probability theory. In essence, Bayes's theory describes a probability of an event dependent on the prior knowledge of conditions that may be relevant to that event. Algorithms of the inference are given in the following equations [26].

The joint probability distribution of a set of variables

$U = \{X_1, X_2 ..., X_n\}$ as:

$$P(U) = \prod_{i=1}^{n} P\left(X_i \setminus P_a(X_i)\right) \quad (1)$$

where $P_a(X_i)$ is the parent set of variables X_i.X_i's marginal probability calculation is as in the following

$$P(X_i) = \sum_{X_j, j \neq i} P(U) \quad (2)$$

The BN utilizes the Bayes theorem to estimate posterior probabilities of the events, given new observations, named as evidence (E), in the shape of the occurrence of incidents, near-misses, etc., as provided in Equation 3 [27].

$$P(U \setminus E) = \frac{P(U, E)}{P(E)} = \frac{P(U, E)}{\sum_u P(U,E)} \quad (3)$$

2.2. FBN

To obtain significant outcomes from the BN structure, assigning the probabilities of the nodes represented in the network is a crucial step. It is pointed out that there are many ways to assign the prior and conditional probabilities of the nodes such as statistical data and literature review. If insufficiency or a high level of uncertainty appears in the statistical data or related literature, the uncertainty can then be eliminated utilizing the fuzzy set theory suggested by Zadeh [28] through employing linguistical values in the evaluation stages. The FBN has been developed to capture the probability values of the nodes in the network structure in the case that statistical data is absent or data is insufficient. Stages of the adopted methodology are shown in the following.

2.2.1. Achieving possibilities from expert judgment

This research has employed expert evaluation. A heterogeneous expert group has been selected. Each expert has work experience with varying levels in different positions in the agency that served Hanjin Shipping exclusively for several years and was working in the agency at the time when Hanjin was bankrupt. These professionals assess the prior and conditional probability of the nodes on the bankruptcy of Hanjin. In this stage, a weighting process is applied, taking the positions, operational experience, and educational qualifications of the chosen experts into account. To show the differences in the assessment, each professional is assigned different points changing between 0 and 5 [29]. Dependent on Equation (4), the weight scores of the experts are calculated as in the following [30].

$$\text{Weighting factor of expert } (W_\mu) = \frac{\text{Weighting score of the expert}}{\text{Sum of all experts' sweighting scores}} \quad (4)$$

2.2.2. Fuzzification

Fuzzy numbers portray the ambiguity in the expert evaluation with the membership function that takes values between 0 and 1. Linguistical variables are utilized to describe uncertain statements in natural languages with definite mathematical terms. There are several types of membership functions existing in the literature. Among these, this paper utilizes a triangular fuzzy membership function, which is one of the most employed membership functions [31,32] to capture prior and conditional probabilities of the root and intermediate nodes. Equation (5) presents the membership function for the triangular fuzzy numbers.

$$\mu_{\tilde{A}}(x) = \begin{cases} 0 & x \leq a_1 \\ \frac{(x-a_1)}{(a_2-a_1)}, & a_1 \leq x \leq a_2 \\ \frac{(a_3-x)}{(a_3-a_2)}, & a_2 \leq x \leq a_3 \\ 0, & x \geq a_3 \end{cases} \quad (5)$$

In this research, a linguistic scale comprising seven terms was selected for expert knowledge elicitation to evaluate the probability distribution of the ambiguity of the nodes. Table 1 provides the linguistic scale and the corresponding fuzzy numbers. The abbreviations of the linguistical statements are codified as VVH, VH, H, SH, M, SL, L, VL, and VVL [33,34].

Table 1. *Fuzzy linguistic scale*

Measurement scale	Triangular fuzzy number		
	a_1	a_2	a_3
VVH	0.95	1	1
VH	0.8	0.9	0.99
H	0.65	0.8	0.95
SH	0.5	0.65	0.8
M	0.35	0.5	0.65
SL	0.2	0.35	0.5
L	0.05	0.2	0.35
VL	0.01	0.1	0.2
VVL	0	0	0.05

2.2.3. Aggregation of the captured fuzzy possibilities

Each expert might take different views about the probabilities of events based on their expertise and occupational experience. Because of this, it becomes crucial to achieve a consensus by taking different expert judgments into account. In this regard, combining the assessment of these expert groups, the similarity aggregation method proposed by Hsu and Chen [29] was employed and provided as follows.

$\widetilde{R1}, \widetilde{R2}$: A pair of expert opinions,

$S_{UV}(\widetilde{R1}, \widetilde{R2})$: The level of agreement (similarity level) of two different expert judgments,

$S(\tilde{A}_1, \tilde{A}_2)$: Degree of similarity between two fuzzy numbers,

$AA(E_u)$: Experts' average agreement

$RA(E_u)$: Relative degree of agreement of experts

$CC(E_u)$: Consensus coefficient (CC) degree of the experts

$\tilde{R}_{AG}$: The aggregated outcome of the expert decisions.

Step (1): The degree of similarity of a pair of experts' judgment is calculated, $S_{UV}(\widetilde{R1}, \widetilde{R2})$ of opinions $\widetilde{R1}$ and $\widetilde{R2}$ of a pair of experts E_U (u=1 to M).

According to this approach, $\tilde{A}_1=(a_{11}, a_{12}, a_{13})$ and $\tilde{A}_2=(a_{21}, a_{22}, a_{23})$ are identified as two triangular fuzzy numbers. The similarity degree between the two fuzzy numbers can then be captured by the defined similarity function as in Equation (6).

$$S(\tilde{A}_1, \tilde{A}_2) = 1 - \left(1/4\right)\sum_{i=1}^{4} | a_{1i} - a_{2i} | \quad (6)$$

Step (2): The calculation of average agreement by M experts is as follows:

$$AA(E_u) = \frac{1}{M-1}\sum_{\substack{U \neq V \\ V=1}}^{M} S(\tilde{A}_1, \tilde{A}_2) \quad (7)$$

Step (3): The degree of relative agreement (RA) is calculated as follows:

$$RA(E_u) \frac{AA(E_U)}{\sum_1^M AA(E_U)} \quad (8)$$

Step (4): The calculation of the CC of the experts is as follows:

$$CC(E_U) = \beta . w(E_U) + (1 - \beta) . RA(E_U) \quad (9)$$

In Equation (9), β takes a value between 0 and 1 and is attributed as the optimism coefficient in the similarity method. In this approach, β (0≤β≤1) is the relaxation factor, which reflects the importance of w (E_u) (weight factor of expert u) on RA (E_u). When β takes the value of 0, the weight factor of the expert is ignored because there exists a homogenous distribution between the experts. When β takes the value of 1, the expert has the same CC degree and weight significance. The assignment of an appropriate β value is crucial and β takes the value of 0.5 in this research [35].

Step (5): Finally, opinions of the experts are aggregated via Equation (10)

$$\tilde{R}_{AG} = CC(E_1) \times \tilde{R}_1 + CC(E_2) \times \tilde{R}_2 + \ldots + CC(E_M) \times \tilde{R}_M \quad (10)$$

2.2.4. Defuzzification

To make an inference in the Bayesian network, it is required to convert the fuzzy numbers into crisp numbers. Fuzzy prior probabilities and conditional probabilities are transformed into crisp numbers through Equation (12). There exist various approaches for the transformation of fuzzy numbers into crisp numbers in the literature such as the weighted average method, center of sums, centroid method maximum membership degree, and center of the largest area [36]. To minimize loss of knowledge and obtain more correct analysis, this study uses the center of area method owing to its applicability and simplicity [37]. For the transformation of fuzzy numbers into definite numbers, Equation (11) and Equation (12) are provided as in the following.

Defuzzification equation: $X^* = \frac{\int \mu_i(x)dx}{\int \mu_i(x)}$ (11)

For a triangular fuzzy number: $\widetilde{A} = (a_1, a_2, a_3)$

$$X = \frac{\int_{a_1}^{a_2} \frac{x-a_1}{a_2-a_1} x\,dx + \int \int_{a_2}^{a_3} \frac{a_3-x}{a_3-a_2} x\,dx}{\int_{a_1}^{a_2} \frac{x-a_1}{a_2-a_1} dx + \int \int_{a_2}^{a_3} \frac{a_3-x}{a_3-a_2} dx} = \frac{1}{3}(a_1 + a_2 + a_3) \quad (12)$$

3. Application of the Fuzzy-Bayesian Method on the Bankruptcy of Hanjin

In this section, the FBN method is applied to model the bankruptcy causes for Hanjin Shipping. Before applying this approach, it is important to reveal and define the bankruptcy causes to establish the Bayes network. This study adopts a case study approach to reveal the probabilistic relationships among the failure causes of the Hanjin Shipping firm. Events in real life are investigated via the case study approach that is applied to different areas such as economics, psychology, and political science [38]. Concerning data collection, this paper employs a mixed approach that utilizes both qualitative and quantitative data. It is indicated that this is quite common in the papers adopting case studies [39].

3.1. Establishing of Variables for the Hanjin Case

In establishing variables, magazines, brokership reports, and previous studies particularly focusing on the bankruptcy causes of Hanjin have been utilized [16,17]. A network of failure causes for the Hanjin case have been elucidated. In building the causes network, a taxonomy including endogenous and exogenous reasons has been employed [17]. After, industrial expert opinions have been achieved for the verification and updating of the last form of variables and definitions of the conditions of all nodes that will be showing up in the BN. To obtain expert opinions, interviews were conducted through telephone conversations. Before performing the interviews, the experts were briefly informed about the target of this study, the BN method, and the course of disclosing the probabilities. In this stage, eight experts have been contacted. These experts have been working for a long time in different liner companies, including the firm that served Hanjin as an agent, and in different positions such as director, vice general manager, and operation manager. Ultimately, 13 root nodes and 7 intermediate nodes that are thought to be contributors to Hanjin's bankruptcy have been determined. Figure 2 provides the reconciled variables and their relationships among each other.

3.2. Identification of Variables

In this paper, causes that led to the bankruptcy of Hanjin were divided into two parts: (1) internal and (2) external. Internal causes have three intermediate nodes: (1) financial flow, (2) commercial management, and (3) ownership management. Meanwhile, external causes have two intermediate nodes: (1) market causes and (2) domestic shipping policies. These intermediate nodes have also root nodes that are illustrated in Figure 2, which will be explained individually below. Furthermore, negative impacts of the bankruptcy on the supply chain of the customers of Hanjin and CKY(H)E alliance are explained as well as government support and merging and acquisition (M&A) as preventative measures.

3.2.1. Internal Causes

Initial attempts that theoretically investigate the causes why businesses fail can be classified into two large streams. These are voluntaristic and deterministic theories that offer opposing elucidations to the causes of firm failure [40,41]. Internal causes are considered as a voluntaristic perspective, and it is argued that since the main decision-makers are managers/owners, the perceptions and actions of the managers/owners are thus the main reason for the demise. In the context of the bankruptcy of Hanjin, internal causal factors are revealed as follows:

3.2.1.1. Company governance structure: Hanjin Group is one of the biggest chaebols and is a family-controlled conglomerate of the Korean economy that changed its shareholding structure seven times between the years of 2008 and 2014 [42]. The shipping arm of the Hanjin Group was separated as a new entity under Hanjin Shipping Holdings and the chairman of Korean Air, Yang-Ho Cho, was appointed as the new CEO of Hanjin Shipping. In the collapse stage of container shipping markets in 2016, Hanjin Shipping could not receive enough support from Korean Air because of the shareholder structure of Korean Air. The governance structure made Hanjin Shipping vulnerable to overcoming financial challenges [17].

3.2.1.2. Working capital: This attributes to the cause arising from cash flow problems that consequently lead to insufficient working capital. If the freight collection period exceeds the period of payments made to third parties such as terminal operators, bunker suppliers, shipping agents, non-operating containership owners, and Protection and Indemnity Clubs, then this eventually leads to cash flow problems that destabilize the financial situation of the firm. In the case of Hanjin, for instance, it was indicated that the firm owed a combined amount of 182 million dollars to container terminal operators and stevedores and 67 million dollars to container leasing companies [43].

3.2.1.3. Issuing bonds: Hanjin Shipping issued corporate bonds to raise capital since after the 2008 financial crisis, banks as traditional financiers of the shipping industry became prudent to provide capital to the industry. The

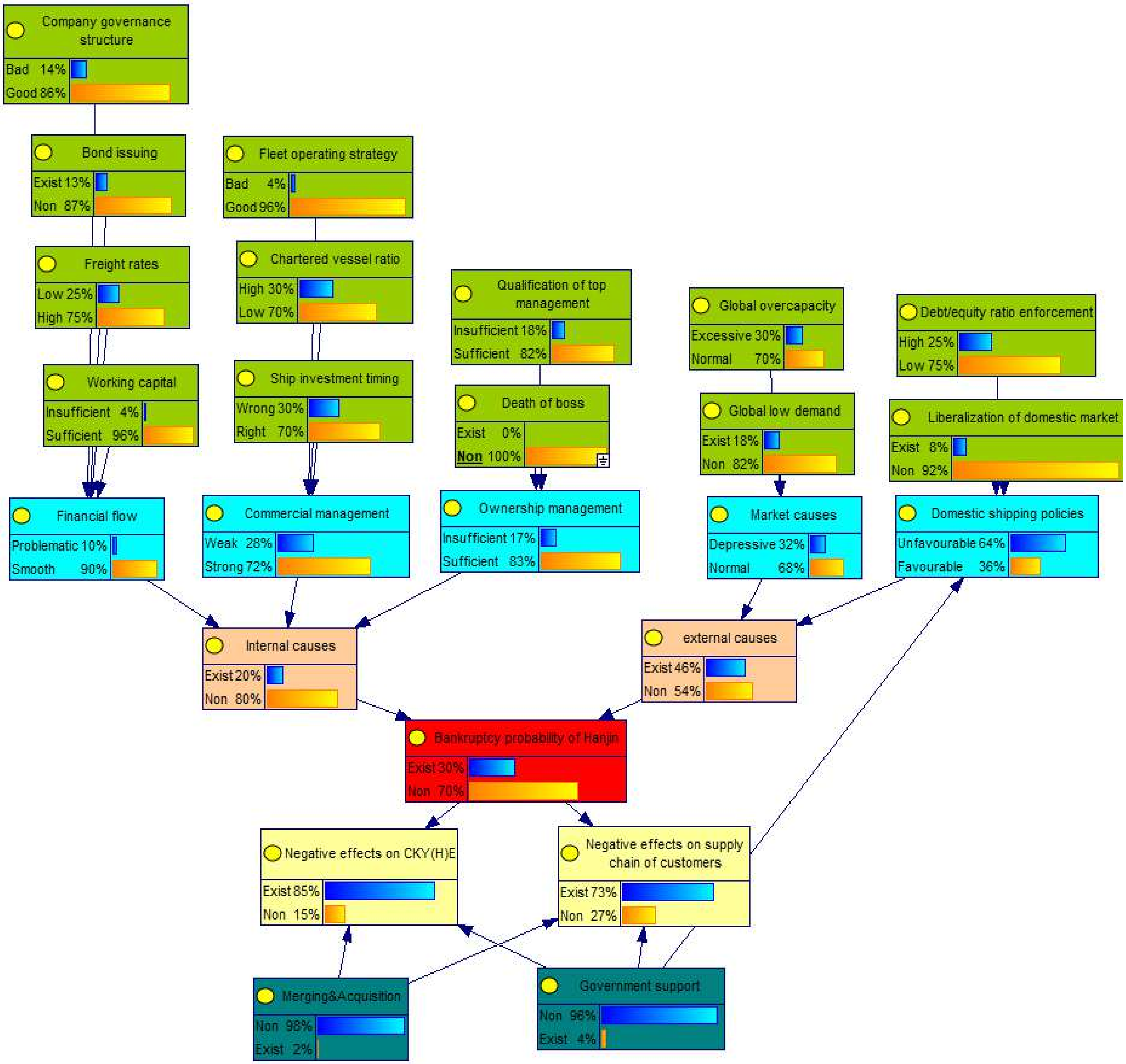

Figure 2. *Modeling of the causes of the bankruptcy of Hanjin under the FBN approach*

FBN: Fuzzy-Bayesian network

face value of the issued corporate bonds reached KRW 700 million on average between 2009 and 2012. Issuing bonds can be regarded as a fast way to obtain capital. However, one disadvantage of it is that compared to bank loans, bonds often have shorter maturity periods. As a reflection of this, it is indicated that most of Hanjin's bonds in 2015 had only two years of maturity and its bonds which would mature within the following three years, had a total value of about KRW 1.4 trillion [16,17].

3.2.1.4. Freight rates: In a depressed stage of a shipping cycle with a sharp decrease in demand, the gap between supply and demand widens significantly leading to a deepening overcapacity in the sector. This increased overcapacity resulted in the reduction of freight rates [32]. In this regard, Dong-Wook et al. [17] pointed out that Hanjin declared general rate increases many times. However, it was not satisfactory because of depressive market conditions.

3.2.1.5. Qualification of top management: One of the reasons that contribute to the bankruptcy of Hanjin can be attributed to the insufficiency of the top management. This phenomenon can be explained to some extent by the fact that Hanjin Shipping is part of a chaebol. Chaebols are operated by family members and generally, the top management is chosen by family members even though family members do not have enough qualifications and industry knowledge. In the case of Hanjin Shipping, after Soo-Ho Cho, a son of the founder, passed away, his wife, Eun-Young Choi, managed the firm between 2006 and 2014. It is pointed out that she had no distinctive management experience and she acknowledged her partial responsibility in the bankruptcy of the firm [16].

3.2.1.6. Personal life of owner: Reasons stemming from an owner's personal life such as death, marriage, divorce, and illness can affect the operations of a company. In the case of Hanjin, group firms were divided into four sons after the death of the founder, which resulted in disputes among siblings and weakening relationships with group firms for surviving on their own [17].

3.2.1.7. Chartered vessel ratio: Carrying a high level of chartered vessels compared to owned vessels results in increased operational costs and decreased profits under depressive market conditions. For instance, Hanjin's charter rates with Seaspan, a non-operating container vessel owner, cost USD 43,000 per day when rates of a spot charter were about USD 25,000 per day [16]. This was the phenomenon that Korean container liner firms experienced negatively due to the debt-equity ratio enforcement of the Korean government. For example, the chartered to owned fleet ratio was about 60% in the container liner industry. This ratio increased to 80% in Hanjin Shipping in 2010 [44].

3.2.1.8. Ship investment timing: It was claimed that several vessel chartering contracts made by Hanjin Shipping were 2 or 3 times more expensive than the average market level just before the collapse stage of the shipping cycle in 2008. The worse one indicates that such chartering fee is about five times higher than the average market price after the 2008 financial recession [16]. This phenomenon can be explained to some extent with the chartering managerial shift. Due to the death of the company's chief executive officer, the ownership was changed in 2007. Several top executives with extensive and long-term chartering experience resigned from the company during the period of the top management transition [18].

3.2.1.9. Fleet operating strategy: To sustain profitability under depressive market conditions, container liner firms are required to take new initiatives. In this way, some mega container firms entered into North-South trade routes containing developed and emerging economies, e.g., Africa and South America, as a niche market. However, Hanjin continued to focus on routes where it showed a strong presence such as the Transpacific route and failed to expand service coverage to niche markets [16].

3.2.2. External Causes

The deterministic perspective argues that managers are restricted by external environmental/industrial constraints that leave them with a real strategic option and therefore, the role of the owners/managers should be ignored. In this approach, external causes are regarded as contributory reasons that consequently lead to bankruptcy, and in the context of the failure of Hanjin, external factors are revealed as follows:

3.2.2.1. Global low demand: It is observed that container shipping experienced the collapse stage of a shipping cycle severely due to decreasing demand especially after the second half of 2015 [45]. No remarkable improvement was observed in markets in the first half of 2016 and China's containerized freight index dropped to a 632-point level in April 2016, which is the lowest level since its inception in 1998 [46].

3.2.2.2. Global overcapacity: Container liner markets have been struggling with overcapacity particularly since the 2008 financial crisis. The opening of the new Panama Canal also worsened the overcapacity plaguing the industry. Due to the opening of new locks of the Panama Canal, some 3,000-5,000 TEU container vessels became less attractive in trade [46]. As a result, the increased surplus capacity left operators with overcapacity reduction options.

3.2.2.3. Debt-equity ratio enforcement: One of the causes of Hanjin's bankruptcy was attributed to the debt-equity ratio regulation initiated by the Korean government, which does not suit well to the container liner industry. For example, the Korean government asked a debt-to-equity ratio of less than 200% in 1998-1999 regardless of the industry type. As a result, liner firms of Korea had to sell some of their vessels to reach that ratio [17]. Similarly, to obtain support from the government-led shipping/shipbuilding fund, it was required to lower the debt-to-equity ratio to 400% in 2016. However, Hanjin Shipping was able to reduce this ratio to 600% by June 2016. Due to this, Hanjin Shipping could not receive support from the specified fund [16].

3.2.2.4. Liberalization of domestic market: Some practices are used to work in favor of domestic shipping firms such as the business license system, cargo waiver system, and cargo reservation system. These applications protected domestic carriers, restricted new entrants to the maritime industry, and also gave priority to Korean-flagged vessels to transport cargoes [47,48]. However, as a reflection of deregulation and liberalization policies that were introduced in the late 1980s, the cargo waiver system was repealed in 1995, the license system for shipping routes was changed in 1996, and the reservation system was repealed in 1999. Deregulation and liberalization policies left Hanjin in a cut-throat competition in the domestic market [17].

3.2.2.5. Government support: In today's globalized world, some countries approach the own liner industry as a key strategic industry and tend to support their shipping lines especially [49]. In this regard, for instance, the Danish government provided a loan of 6.2 billion USD for Maersk in 2011. However, Hanjin could not receive financial support from the Korean government in 2016 [17]. Also, Yang-ho Cho, which is the head of Hanjin Group, the parent company of Hanjin Shipping, claimed that their shipping branch had not competed on equal terms with their rival container lines because the majority of them had obtained the support of their governments [50].

3.2.2.6. M&A: The bankruptcy of Hanjin has caused the acceleration of the M&A process in the liner industry to obtain enough market share and increase operational efficiency concerning the concept of a size-related scale of the economy [51]. In this regard, for instance, Cosco merged with OOCL and Hapag-Lloyd merged with United Arab Shipping Company [52,53].

3.2.2.7. Negative impacts on the supply chain of customers: The bankruptcy of Hanjin had a ripple effect throughout the customers' supply chain. A sizable amount of customers whom Hanjin used to serve can be considered as time-sensitive customers since they agreed to pay a high freight rate in exchange for the fast delivery service of Hanjin. However, some customers operating in the clothing industry missed the fashion season and some could not even receive their cargo. Because of the disruptions, customers became cautious in their dealings with container lines [52].

3.2.2.8. Negative impacts on CKY(H)E alliance: Carriers share slots under highly-structured strategic alliances and Hanjin had been involved in the CKY(H)E alliance before bankruptcy. Not only shippers but also Hanjin's alliance partners, Cosco, Evergreen, Yang Ming, and K-Line, scrambled to determine what would occur to their cargo on board Hanjin vessels. As a CKY(H)E partner, the K-Line was the most exposed, with container boxes on 63 Hanjin vessels [54].

3.3. Establishing Prior and CPTs

Prior probabilities and CPTs were created for each node existing in the BN after establishing the BN graphical structure and designating the condition of the nodes. To perform this, an excel file that includes the definitions of the bankruptcy causes, conditions of the nodes, and questions to reveal the probabilities was delivered to the experts. The fuzzy linguistic scale was exploited as given in Table 1. In this stage, an assessment of the probabilities between node relations was obtained from three experts. Since the qualification of professionals is considered different, a weighting process is necessary to reveal their differences in the assessment process. Therefore, the occupational position, work experience, and level of education as weighting criteria are taken into account, and each variable is assigned a value ranging from 0 to 5.

Table 2 provides the details that are considered for the weighting values of the experts, while Table 3 shows the details for the experts and calculations of the weighting process [35].

The GeNle version 2.2.1 software was used to utilize the data in BN modeling. Before exploiting the GeNIe program, expert judgments that are achieved on the ground of linguistic expression were fuzzified through triangular fuzzy members. Following that operation, a similarity aggregation method that is developed by Hsu and Chen [29] was used to reach a compromise about expert opinions. Since expert opinions were obtained on a fuzzy scale, it is required to transform them into crisp numbers through the defuzzification process by employing the center of area approach as provided in equations 10 and 11. All these transactions were conducted in an MS Office Excel file so that the data would be prepared for proceeding with the GeNle software. Experts provided fuzzy conditional probabilities for intermediate and leaf nodes. Because of limited space, just a part of a CPT of the commercial management node is provided in Table 4.

Table 2. *Criteria for weighting*

Constitution	Classification	Score
Professional position	Director	5
	Operation manager	4
	Logistics manager	3
	Regional manager	2
	Territory sale executive	1
Occupational experince	More than 15 years	5
	11 to 15	4
	6 to 10	3
	3 to 5	2
	Less than 3 years	1
Educational level	PhD	5
	Master	4
	Bachelor	3
	HND	2
	School level	1
HND: Higher National Diploma		

Table 3. *Details of experts and calculations of weighting scores*

Expert Level								
Expert no	**Professional position**	**Experience**	**Education level**	**Weighting factor**			**Tw**	**Weighting score**
1	Operation Manager	24	Bsc	4	5	3	12	0.3428
2	Logistics Manager	17	Bsc	3	5	3	11	0.3142
3	Director	15	Bsc	5	4	3	12	0.3428

Table 4. *Table of conditional probabilities for the commercial management intermediate node*

Chartered vessel ratio	**High**				**Low**			
Ship investment timing	**Wrong**		**Right**		**Wrong**		**Right**	
Fleet operating strategy	Bad	Good	Bad	Good	Bad	Good	Bad	Good
Weak	0.986	0.969	0.336	0.183	0.816	0.663	0.031	0.014
Strong	0.014	0.031	0.664	0.817	0.184	0.337	0.969	0.986

3.4. Sensitivity Analysis

The sensitivity analysis is of vital importance in the probabilistic assessment. The effect of the precautions taken to hinder the undesired event is revealed via the sensitivity analysis, and variables are ranked on the ground of their effects on the target node [55]. A sensitivity analysis was conducted for all nodes, and the outcomes are shown in Table 5. Based on the sensitivity analysis, after internal causes and external causes, the commercial management, ownership management, ship investment timing, and qualification of the top management are the major contributing variables that account for the bankruptcy of Hanjin. After, sensitivity analyses for all child-parent node combinations were carried out. Only the financial flow and commercial management causes sections were incorporated as in Table 6.

Furthermore, sensitivity analyses are performed to evaluate the bankruptcy of Hanjin in terms of the negative effects on the CKY(H)E alliance and the supply chain of customers in connection to the prevention barriers that are M&A and support of government measures (Table 7).

4. Findings and Discussion

In this research, a cause-consequence approach was conducted for the bankruptcy of the Hanjin case under the FBN method. Variables are established based on the literature review and confirmed by experts. The probability of the bankruptcy of Hanjin was calculated as 30% by utilizing the BN (Figure 2). It is revealed that this ratio increases to 97% when internal and external causal factors exist together (Figure 3). Findings of this paper support the literature body suggesting that an integrative approach is a more powerful way of explaining the causal mechanism of bankruptcy than internal and external do solely [56-58].

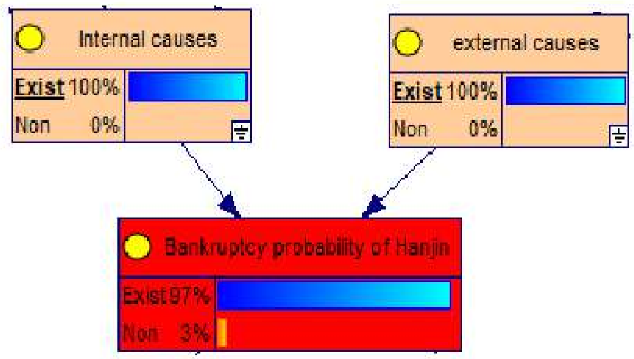

Figure 3. *Conditional probabilities for the bankruptcy of the Hanjin node*

According to Hall [59], Gaskill et al. [60], and Arditi et al. [61], internal causes were the most frequent causes that account for firm failure. Whereas, Baldwin et al. [62] point out that internal and external causes carry equal importance in explaining the bankruptcy of a firm. Taking the sensitivity analysis results into account, it is observed that internal causes have the largest impact on the occurrence of the bankruptcy of Hanjin. As provided in Table 5, the variation of the leaf node (bankruptcy of Hanjin) occurrence probability in the network is 62%. Thus, it is revealed that the outcomes of this study are in parallel with the studies of Hall [59], Gaskill et al. [60], and Arditi et al. [61]. Internal causes are followed by weak commercial management, which has the second strongest effect on the occurrence of the bankruptcy of Hanjin with a variation of the leaf node (bankruptcy of Hanjin) occurrence probability in the network of 32.9%.

Based on the sensitivity analysis, after internal causes and weak commercial management, the external causes, wrong timing of ship investment, and insufficient ownership management are the major contributing variables that

Table 5. *Sensitivity analysis for all nodes*

Nodes	Condition 1st	Prior %	Change node state 1 100%	Change node state 2 100%	Bankruptcy prior probability	Bankruptcy posterior probability state 1 100%	Bankruptcy posterior probability state 2 100%	Change of probability
Company governance structure	Bad	0.140	100	100	0.305	0.337	0.299	0.038
Bond issuing	Exist	0.134	100	100	0.305	0.317	0.303	0.014
Freight rates	Low	0.249	100	100	0.305	0.317	0.3	0.017
Working capital	Insufficient	0.044	100	100	0.305	0.325	0.304	0.021
Fleet operating strategy	Bad	0.044	100	100	0.305	0.328	0.304	0.024
Chartered vessel ratio	High	0.303	100	100	0.305	0.353	0.284	0.069
Ship investment timing	Wrong	0.301	100	100	0.305	0.464	0.236	0.228
Qualification of top management	Insufficient	0.179	100	100	0.305	0.384	0.287	0.097
Death of boss	Exist	0.168	100	100	0.305	0.344	0.297	0.047
Global overcapacity	Excessive	0.301	100	100	0.305	0.398	0.265	0.133
Global low demand	Exist	0.179	100	100	0.305	0.312	0.303	0.009
Debt/Equity ratio enforcement	High	0.247	100	10	0.305	0.339	0.294	0.045
Liberalization of domestic market	Exist	0.076	100	100	0.305	0.325	0.303	0.022
M&A	Non	0.983	100	100	0.305	0.305	0.305	0.000
Government support	Non	0.956	100	100	0.305	0.308	0.237	0.071
Financial flow	Problematic	0.096	100	100	0.305	0.403	0.294	0.109
Commercial management	Weak	0.276	100	100	0.305	0.543	0.214	0.329
Ownership management	Insufficient	0.218	100	100	0.305	0.434	0.269	0.165
Market causes	Depressive	0.316	100	100	0.305	0.413	0.255	0.158
Domestic shipping policies	Unfavorable	0.644	100	100	0.305	0.346	0.231	0.115
Internal causes	Exist	0.209	100	100	0.305	0.801	0.174	0.627
External causes	Exist	0.458	100	100	0.305	0.469	0.166	0.303

M&A: Merging and acquisition

Table 6. *Sensitivity analysis for the financial flow cause & commercial management causes*

Child node	Parent nodes	Condition 1st	Prior %	Change node state 1 100%	Change node state 2 100%	Financial flow prior probability	Financial flow posterior probability state 1 100%	Financial flow posterior probability state 2 100%	Change of probability
Financial flow	Company governance structure	Bad	0.140	100	100	0.096	0.392	0.047	0.345
	Bond issuing	Exist	0.134	100	100	0.096	0.212	0.078	0.134
	Freight rates	Low	0.249	100	100	0.096	0.214	0.057	0.157
	Working capital	Insufficient	0.044	100	100	0.096	0.282	0.087	0.195
Commercial management causes	Fleet operating strategy	Bad	0.044	100	100	0.276	0.347	0.273	0.074
	Chartered vessel ratio	High	0.303	100	100	0.276	0.424	0.212	0.212
	Ship investment timing	Wrong	0.301	100	100	0.276	0.761	0.068	0.693

Table 7. *Consequence analysis for the negative impact on the alliance*

Child node	Parent nodes	Condition 1st	Prior %	Change node state 1 100%	Change node state 2 100%	Negative effects on CKY(H)E prior probability	Negative effects on CKY(H)E posterior probability state 1 100%	Negative effects on CKY(H)E posterior probability state 2 100%	Change of probability
Negative impact on alliance	Bankruptcy	Exist	0.305	100	100	0.847	0.948	0.803	0.145
	M&A	Non	0.017	100	100	0.847	0.854	0.463	0.391
	Government support	Non	0.044	100	100	0.847	0.871	0.347	0.524
Negative impact on the supply chain of customers	Bankruptcy	Exist	0.305	100	100	0.734	0.985	0.624	0.361
	M&A	Non	0.017	100	100	0.734	0.741	0.344	0.397
	Government support	Non	0.044	100	100	0.734	0.754	0.294	0.460
M&A: Merging and acquisition									

account for the bankruptcy of Hanjin. External causes lead to a 30% variation on the occurrence probability of the bankruptcy of Hanjin, which was followed by wrong ship investment timing, which has the highest impact on the explanation of the commercial causes with a 69% variation impact on the occurrence probability of commercial management causes (Table 6). Outcomes of this paper are in line with Shin et al. [18] as it is indicated that chartering contract management featuring a long period and chartering of mega-container vessels over 10,000 TEU rather than owning was regarded as the major causes for Hanjin's demise. To mitigate the effects of the weak commercial management and specifically wrong ship investment timing, container liner firms should establish an effective chartering policy that implies a lessening of the chartering period and decreasing of the ratio of chartered mega-container vessels in the fleet composition, since these pose a greater risk under depressive market conditions that Hanjin had experienced. Wrong ship investment timing is followed by insufficient ownership management with the node exhibiting a 16% variation on the occurrence probability of the bankruptcy of Hanjin. To mitigate the effects of the causal factors of insufficient ownership management, it is recommended that liner firms should set up an effective succession planning policy that identifies and prepares potential candidates for high-level managerial positions that become unoccupied because of death, resignation, retirement, etc. In the case of Hanjin, the ownership was changed due to the passing of the CEO in 2007, and various high-level managers having a long period of chartering experience resigned from the firm in the stage of transition of the top management. As a result, this undermined the Hanjin's capability to maneuver in the depressive market environment [16].

Elaborating on the financial flow causes, the bad company governance structure has the largest effect on the occurrence of the problematic financial flow since this node leads to a 34% variation on the occurrence probability of the financial flow factor (Table 6). This is followed by insufficient working capital. Low freight rates have the least impact on the occurrence probability of the problematic financial flow (Table 6).

Furthermore, the bankruptcy of Hanjin is found to have a significant negative impact on the CKY(H)E alliance and the supply chain of customers of 85% and 73%, respectively. If the occurrence of the bankruptcy of Hanjin is realized, the negative impact on the CKY(H)E alliance is then increased from 85% to 94.8%. Similarly, this ratio is increased from 73% to 98.5% for the negative effects on the supply chain of customers. Based on this, it can be inferred that the impact of the bankruptcy of Hanjin on the supply chain of customers is higher than that of the alliance. After Hanjin's bankruptcy, carrier financial stability has been a very important issue for the supply chains. After, the consequences of Hanjin bankruptcy are evaluated and associated with prevention barriers (M&A and government support) that aimed to prevent Hanjin from bankruptcy. If the M&A activity had been performed, negative effects on the CKY(H)E alliance could have been reduced from 85% to 46%. Similarly, if the South Korean government had supported Hanjin, then the negative effects on the CKY(H)E alliance could have been reduced from 85% to 35%. Therefore, it can be inferred that government support could have been a more influential measure to mitigate the negative effects on the CKY(H)E alliance. On the other hand, if the M&A measure had been taken, then the negative effects on the supply chain of customers could have been decreased from 73% to

34%. Similarly, if Hanjin had been supported by the Korean government, the negative effects on the supply chain of customers could have been decreased from 73% to 29%. Thus, it can be deduced that government support could have been a more effective measure to mitigate the negative effects on the supply chain of customers.

5. Conclusion

This study uniquely presents the probabilistic relationships among the causes that led to the bankruptcy of Hanjin and contributes significantly to the bankruptcy causes literature through handling a case study approach utilizing the Fuzzy-BN approach. It is found that an integrative approach is a stronger way to explain the bankruptcy event. Compared to the deterministic approach, the results of this research favor the voluntaristic perspective. Furthermore, it is revealed that weak commercial management, external causes, and wrong ship investment timing are found as the major contributing variables for bankruptcy. As a preventative measure, government support is revealed to be a more influential measure to mitigate the negative effects on the CKY(H)E alliance and supply chain of customers compared to the M&A initiative. In this regard, the findings of this research are considered to provide useful insight for container shipping stakeholders as they can be assisted to better understand the bankruptcy causal mechanism and to differentiate their efforts to mitigate the failure risk. In this research, the bankruptcy of Hanjin is considered as a static event and in a further study, external and internal causes can be examined as a dynamic process.

Authorship Contributions

Concept design: M. Aydın, B. Kamal, Data Collection or Processing: B. Kamal, Analysis or Interpretation: M. Aydın, B. Kamal, Literature Review: B. Kamal, Writing, Reviewing and Editing: M. Aydın, B. Kamal.

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Decision-making under Risk: A Ship Sale and Purchase Problem by Utilizing Cumulative Prospect Theory

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Abstract

Decision-making is often performed intuitively, yet formal decision-making by logical reasoning is needed for crosschecking or advocating despite its being burdensome and comprehensive. Prescriptive and descriptive approaches have been introduced for formal decision-making. Former regards decision makers as, metaphorically, rational computers whereas latter considers the human perception of value and probability differentiating in case of loss and gain. To the best of our knowledge, no research has been conducted on a ship sale and purchase problem based on a descriptive method to explain human risk aversive nature, perception of value, and probability. This study is therefore unique in the academic literature. This research includes the presentation of formal decision-making, related approaches, methods, and theories, the application of cumulative prospect theory (CPT) on a ship sale and purchase problem. An empirical study has been created and modeled, including statistical data concerning fuel oil prices and freight rate profit margins. A voyage estimation based on the empirical study is performed, calculations are carried out by utilizing the expected value method and CPT. Results obtained are quite useful for a better understanding formal decision-making, prescriptive, and descriptive approaches, and interpreting status-quo in demand for bulk carriers.

Keywords: Sale and purchase, Bulk carrier, Formal decision-making, Cumulative prospect theory

1. Introduction

People frequently stand at the crossroads where they need to assess their alternatives and choose one that fulfills criteria as a good solution. Decision-making is therefore related to a particular problem, alternatives, consequences, and a set of subjective criteria. Even though decisions are made intuitively, enterprises, or companies require decisions to be made primarily for justification. There have been two approaches asserted for formal decision-making: rational and behavioral decision-making. Rational decision-making is prescriptive and handles each situation as involving every piece of information required; therefore, any problem could be solved solely by intelligence. Behavioral decision-making is descriptive and rather concerned with the human perception of value, gain, loss, or meaning of uncertainties and probabilities [1].

Decisions, alternatives, and states of nature are visualized by several methods, including decision tables, decision trees, or programming languages. A decision table comprises a stack of data that usually serves as a basis for knowledge acquisition. Its primary purpose is to present decision variables, states of nature, and consequences in a matrix form. Decision variables constitute rows and states of nature form columns where consequences correspond to the intersection of rows and columns. A decision tree is a useful tree-like representation of a complex problem comprising decision nodes, alternatives, and related consequences. It is constructed rightward, evaluated leftward, and made rightward. Programming language is an algorithm benefiting from computer languages to fulfill a certain assignment. Selection of the most suitable visualization method for formal decision-making is often related to the complexity of the problem in question,

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expectation, and ability of the practitioner. Programming languages are often too advanced for most decision makers; therefore, the option would generally be limited to decision tables and decision trees. A decision tree is the standard method for holistic and comprehensive decision-making where a decision table is more suitable for the first step for visualization of knowledge acquisition. The size of a decision table corresponding to a decision analyzed by a decision tree would be too large and unpractical [2]; therefore, common sense during formal decision-making is to construct a decision tree.

Despite a considerable growth of 4.1% in 2019, the highest since 2014, global maritime trade has been severely affected by the coronavirus pandemic. Maritime trade has encountered short- and long-term crises arising from changing status-quo due to the pandemic, reshaping of the supply chain, and globalization patterns. Even though freight rates were observed to increase between January and June 2020 compared to 2019 for most trade routes, rates and ship supply capacity have been rearranged and kept at a viability level to preserve the continuation of global maritime transportation. Therefore, risk assessment and formal decision-making are becoming an utterly higher priority [3]. Shipowners primarily rely on chartering their ships for cargo transportation as a business model during booming periods of shipping cycles. Yet, the global financial crisis of 2008 and the coronavirus pandemic revealed a fact once more that selling existing ships and purchasing new ones, if deemed profitable, would be a smart strategy as implemented by many shipowners from prominent countries in maritime trading. Selling and purchasing ships could provide a more robust growth for shipowners or shipping companies than solely positioning for cargo transportation if they would be in the right place at the right time [4]. However, shipping trade contains considerable uncertainties like fuel prices, transportation demand, global financial status, production rates, and freight rate profit margins; therefore, it is not always easy to foresee the shipping cycle and the right decision whether to hold, sell, or sell and purchase. Violent competition, demand for transportation of a particular commodity, and unpredictability would easily be the driving force for a shipowner to make formal decision-making for the subsequent action based on the subjective perception of value and probabilities of outcomes.

This study comprises four sections: expected value method, expected utility theory, prospect theory, and cumulative prospect theory (CPT), as explained in Section 2. CPT is opted for the context of this study as supported by the literature review. An empirical study structured over bulk carriers of different sizes is described in Section 3, with relevant data. Bulk carriers are preferred as objects of the empirical study because dry bulk freight rates have been quite volatile in the past three years due to disruptions caused by pandemic conditions and imbalances in supply and demand [3]. CPT is then applied to the empirical study, and results are analyzed. Implications and conclusions are presented in Section 4. This study is expected to be the first contribution in the academic literature by introducing a descriptive decision-making method like CPT on a ship sale and purchase problem and be a remarkable formal decision-making analysis example.

2. Research Design

This section includes a brief introduction to formal decision-making, prescriptive, and descriptive approaches, expected value, expected utility theory, prospect theory, and CPT. Historical and evolutionary relevance of these methods are elucidated. Decision-making and application of CPT on ship sale and purchase activities and shipbuilding industry are reviewed in the academic literature further in this section.

2.1. Expected Value, Expected Utility Theory, and Prospect Theory

Decision-making is defined as selecting a set of alternatives with no shared characteristics. Choosing an alternative would have consequences based on the state of nature or the possibilities. Decisions may be made in under certain, risky, or uncertain environments. Decision-making under conditions in which alternatives and their outcomes are known as decision-making under certainty. Decisions influenced by probabilities are referred to as risky decisions. In this context, the risk does not always imply danger but also an opportunity or a gain. Decision-making under uncertainty is a classification similar to that made under risk, yet whether probabilities are not known or alternatives, probabilities, or consequences are not cognized tacitly. The former is known as decisions made under ambiguity, and the latter is recognized as decisions made in ignorance [5].

Formal decision-making comprises prescriptive and descriptive approaches. Former considers decision-making as a rational process strictly bound to predefined prescriptions while latter studies systematic revelations between such rational individuals [6]. However, "rationality" has limitations. It is claimed that a decision maker lacks complete information and computational skills and thus is easily influenced by bias, fallacies, or makes the wrong choice. This natural boundary of human thinking is called bounded rationality [1].

Expected value is the most common prescriptive method in evaluating a decision. It has its origins back to the 17th century as introduced by famous mathematicians Pascal and Fermat that preferability of an alternative is related with the Equation (1), where p_i stands for probability and a_i for the payoff (i.e., consequence) that is usually defined in amount of money of the outcome "i" belonging to an alternative (a). This methodology is quite simple and straightforward [7].

$$EV(a) = \sum_{i=1}^{n} p_i \cdot a_i \quad (1)$$

Expected value lacks to include human attitude toward risky situations. Bernoulli had uncovered this argument with St. Petersburg Lottery, indeed a paradox, in the 18th century. In this paradox, one would be asked how much he/she would be eager to pay once to participate in a heads or tails game in which a fair coin is used. If the tails side comes up, the player will get a prize (say €2) where if heads are observed, the player will have a chance to play the game once more. If the coin were tossed for n times, the player would get €2^n. Even though the expected value of playing the game seems to be infinite, the common human mind would instantly, without deliberately considering, only be willing to pay very small amounts of money to participate in a game or even decline the offer. Bernoulli had clarified this phenomenon that an individual would intuitively place a personal rather subjective value on monetary outcomes; that is, the money in one's pocket is more attractive when there is a probability of gaining even though the expected value of the game is too high. This value for human subjective perception is called "utility," and the total outcome of the game is the expected utility [8]. Expected utility theory is asserted based on this phenomenon and is a prescriptive method in which decision maker's choice is related to their risk-seeking or risk-averse nature [9]. Expected utility of an alternative is calculated as per Equation (2), where p_i is the probability, and the term $u(a_i)$ is the utility of a consequence. The utility function is related to decision maker's subjective preferences and risk attitude. There is no specific way to formulize or standardize a subjective utility function.

$$EU(a) = \sum_{i=1}^{n} p_i \cdot u(a_i) \quad (2)$$

It is claimed that decision makers are likely to give more weight to losses than gains, and people become risk aversive in case of gaining and risk-seeking in case of losing [10]. Expected utility theory lacks to reflect this human behavior during decision-making, leading to the development of prospect theory. As introduced by Tversky and Kahnemann [11] in 1979, prospect theory is a descriptive approach in which outcomes of an alternative are evaluated based on a reference point, a subjective breakeven point defined by the decision maker. A gain or loss would be referred to according to deviation from that point. A weighting function presents the weight of probabilities, and a value function gives value of an outcome. Prospect value of an alternative is calculated as per Equation (3) where "a" is an alternative, a_i is an outcome, the term $v(a_i)$ is the value of an outcome as depicted by Figure 1, the term $w(p_i)$ is the weight of the probability as presented on Figure 2. V(a, p) is the prospect of an alternative [8].

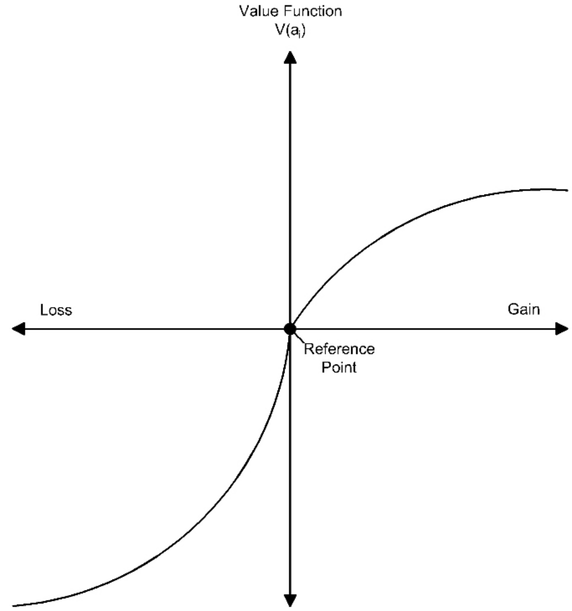

Figure 1. *Value function*

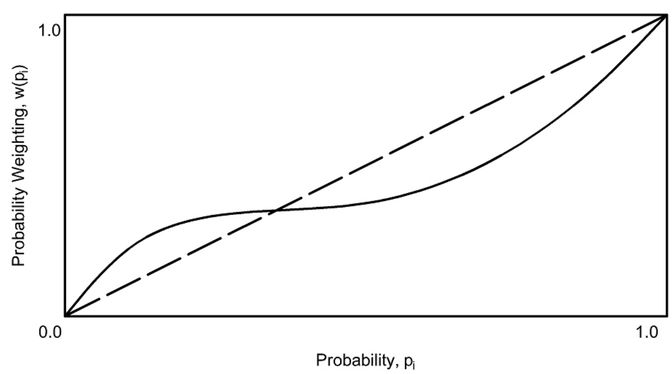

Figure 2. *Probability weight function*

$$V(a, p) = \sum_{i=1}^{n} w(p_i) \cdot v(a_i) \quad (3)$$

2.2. Cumulative Prospect Theory

CPT is a descriptive method used to describe decisions made under risk applicable for any number of outcomes. In this theory, different weights correspond to probabilities in the case of gains and losses. Value and weighting functions could be explained by diminishing sensitivity and loss aversion. This theory is also perfect for explaining the fourfold pattern of risk attitudes [11], as summarized in Table 1.

Table 1. *Fourfold pattern of risk attitudes [8]*

	Gains	Losses
Low probability	Risk-seeking	Risk-averse
High probability	Risk-averse	Risk-seeking

This theory assumes that an alternative arises from positive and negative outcomes in a total number denoted by "n." Outcomes are put in order first regarding gain or loss.

Losses are ranked from i=1 to i=m and gains from i=m+1 to i=n. Cumulative prospect value of an alternative is calculated as per Equation (4) [8].

$$\text{CPT}(a) = \sum_{i=1}^{m} v(a_i) \cdot w^{-}(p_i) + \sum_{i=m+1}^{n} v(a_i) \cdot w^{+}(p_i) \quad (4)$$

The risky alternative is then assessed by the sum of expected rank dependent utility of loss and gain outcomes and shown as CPT (a). Value function of the outcomes is determined based on the empirical two-part power function to reflect the common sense of human exception of value as per Equation (5) [8].

$$v(x_i) = x_i^{0.88} \text{ for } x_i \geq 0$$
$$v(x_i) = -2.25 \cdot (-x_i)^{0.88} \text{ for } x_i < 0 \quad (5)$$

The probabilities of ranked outcomes would be accumulated from left to right for losses and from right to left for gains. If the table is organized vertically, it would be from top to bottom for losses and vice versa for gains. The cumulated probabilities are then transformed by a probability transformation given by Equation (6) [8].

$$g(p) = \frac{p^{\delta}}{(p^{\delta}+(1-p)^{\delta})^{(1/\delta)}} \ (\delta=0.61 \text{ for gains}, \delta=0.68 \text{ for losses}) \quad (6)$$

The transformed accumulated probabilities are decumulated, and weighed probability of each outcome is obtained. Value and weighted probabilities are then multiplied for each outcome, summed up, and the CPT-value of the alternative is found [8].

2.3. Literature Review

Maritime trading is defined as the transportation of packaged or non-packaged commodities, material, goods, equipment, machinery, livestock, or passengers between ports on a local or global scale that is performed wholly or partly at sea and ocean [12]. It is highly influenced by the changes in financial trends, politics, globalization, and manufacturing. Besides harsh financial crises and political instability, maritime transportation is considered profitable for carrying commodities in high volume and long distances. It is also considered one of the most globalized businesses enabling fast cargo transportation between offshore companies, far regions, and countries. Furthermore, a close relationship between maritime trade and world gross domestic product reveals the vital importance of maritime transportation for the global economy [13].

Dry bulk cargo could be a homogenous, non-packaged solid carriage that is easily loaded, carried, and unloaded in large quantities into or from the holds of a vessel specialized for this purpose or storage [14]. Bulk carriers are vessels mainly designed to carriage such cargoes [15]. Common dry bulk cargoes are distinguished in the form of bauxite, bulk minerals, cement, chemicals and cokes, agricultural products, grains, ores, wood chips, refrigerated goods, livestock and animal products, unitized goods, wheeled and heavy units [16]. Bulk carriers could be utilized in liner or tramp shipping. In liner shipping, large vessels are employed on fixed routes and schedules, whereas in tramp shipping, smaller vessels in capacity are utilized in no fixed routes or schedules but to any destination depending on availability and profitability of opportunity. Most of the maritime transportation is performed via tramp shipping [17]. Significance of dry bulk cargo has been increasing over the last forty years in contrast to liquid bulk cargo. This could be explained by the growing appetite of financial regions in developing countries for coal and iron in the steelmaking process and industrial activities [13].

Decision-making for ship sale and purchase activities has attracted many researchers. Most preferred methods include but are not limited to real options analysis (ROA), analytic hierarchy process (AHP), and fuzzy analysis. Fuzzy methods are also combined with other approaches. Among these, ROA is one of the most favored method. One of the studies includes applying net present value (NPV) and ROA on a case study to reveal their differences. NPV considers the present value of investment whereas ROA scrutinizes uncertainty factors like dry bulk freight rate and ship price over an entire ship investment period. ROA also presents investors with different scenarios and options like abandoning or deferring the investment. The study reveals different results with NPV and ROA, highlighting the importance of uncertainty factors while involved in a ship sale and purchase decision-making process, noting that the study assumed subjective judgment of decision makers as neutral [18]. Along with ROA, fuzzy is also a highly appreciated method in which fuzzy algorithm is combined with ROA's primary purpose to deal with uncertainties that ship investment inherits. The hybrid method is analyzed through a case study from a shipping company [19]. Fuzzy set theory is applied to another study by evaluating the NPV of ships, profitability, and period of payback supported by a case study [20]. Fuzzy extended

Technique for Order Preference by Similarity to Ideal Solution (fuzzy-TOPSIS) Multi-Criteria Decision Analysis is a remarkable study practiced on a bulk carrier purchase process. Ship price, deadweight, energy consumption, engine power, age, and crane capabilities are defined as criteria for this purchase process based on questionnaires conducted with experts [21]. In another paper, the authors examined both financial and technical factors (e.g., speed, port entry limitations, etc.). They applied fuzzy-TOPSIS method for a better realistic approach for ship investment decision-making problems [22]. A combination of fuzzy and Monte-Carlo simulation is also created to decrease uncertainties inherited by variables. Based on historical data collected for panamax size bulk carriers, the model is evaluated to visualize the effects of length of the investment term, loan size, and freight based on predefined scenarios [23]. Apart from ROA and fuzzy, AHP is broadly preferred by researchers. In one of the studies, the authors defined three main criteria (business, market environment, and policy) and twelve sub-criteria for a second-hand ship sale and purchase decision-making problem. Pairwise comparison matrices are prepared as per questionnaires conducted with professionals and experts from the Korean shipping industry. It is found that the financial status of the market share, potential of new markets, and envisaged share of the market are the driving force of such a decision-making problem [4]. A separate study on Handymax and panamax cases depends on predefined market scenarios based on surveys made with financial and technical experts [24].

Based on the literature review, it is concluded that no research is encountered utilizing CPT on maritime trading and ship sale and purchase activities, but few studies are present on the shipbuilding industry. In a research, CPT is applied to define dry-docking interval of ship hull girders [25]. The authors state that dry-docking period for a ship involves uncertainties including different rates of corrosion growth, properties related to material and geometry, loading differences, and high correlation with the economical operation of the ship in question. They further claim that minimizing the expected life-cycle cost (MELC) method is eligible to be employed to determine the period. Yet, it cannot reflect the shipowner's attitude toward risky situations. The risk here is risk-averse by shortening the period to prevent possible structural damages due to corrosion or risk-seeking by extending the interval to reduce downtime during the dry-docking process. It is concluded that the period obtained by CPT could yield a shorter period than MELC. A similar study is performed on navigation safety improvement measures by utilizing CPT, claiming that such measures are usually taken by decision makers with bounded rationalities and highly regarded with their risk-averse or risk-seeking behavior. The authors defined the measures considered for shipping navigation safety investments, defined value function and probability weighting functions, mathematically modeled the problem and educed that CPT applies to such decision-making problems regarding terms like reference point and risk perception of decision makers [26].

3. Empirical Study

This section generates an empirical study to apply the expected value method and CPT to a ship sale and purchase problem. The problem is primarily defined, and alternatives to the decision are rendered. A decision tree is subsequently structured. Data related to the problem is gathered, tabulated, and statistics for states of nature are analyzed to reach probabilities inherited by alternatives. A voyage estimation is performed to calculate the payoff values of each consequence of alternatives. CPT is finally implemented in the empirical study, and results are discussed.

3.1. Purpose

Different results are generally expected through prescriptive and descriptive approaches used on the same formal decision-making problem. This deviation is more obvious in maritime trade, where the perception of value is dramatically subjective and decisive. The primary purpose of this empirical study is to apply a descriptive formal decision-making method to a shipowner's sale and purchase problem then subsequently compare the results with those obtained by a prescriptive method. Expected value method and CPT are deemed suitable for such a problem in which the shipowner is to decide whether to continue trading with his existing ship or conduct a sale and purchase process. Within this research, Alternative a_1 is to keep existing bulk carriers, Alternative a_2 is to sell the existing ship and purchase two smaller bulk carriers, and Alternative a_3 is to sell the existing ship and purchase three smaller bulk carriers. Figure 3 presents decision tree created for the empirical study.

3.2. Data

Data for six bulk carriers are gathered to be benefited from the decision-making problem within the context of this empirical study. Ship no: 1, 2, and 5 are taken identical for ease of calculation. Table 2 summarizes ship data.

Notably, a shipowner's sell and purchase decision is highly related to the owner's financial status, fluctuations in commercial fleet, local, regional and global production and trading capacity, cargo transportation demand, and change in oil price and freight rate [4]. However, in this study, only fuel oil price, and freight rate profit margin will be considered as probabilities for calculation.

It was recorded in 2019 that the most prominent countries in global bulk trade are located in the Southeast Asia region. Some champions of global bulk trade in that year situated in the region and their shares in global trade are China (53% of steel export, 51% of steel import, 72% of iron ore export, 19% of coal import), Australia (57% of iron ore import), Indonesia (35% of coal export) [3]. Forty months of statistics for Singapore oil prices are preferred to reflect status-quo in bulk trading for the context of the study and examined in Table 3 for determining fuel of probabilities [29]. IFO380 interval values are determined considering the minimum and maximum values of the statistics in Table 3.

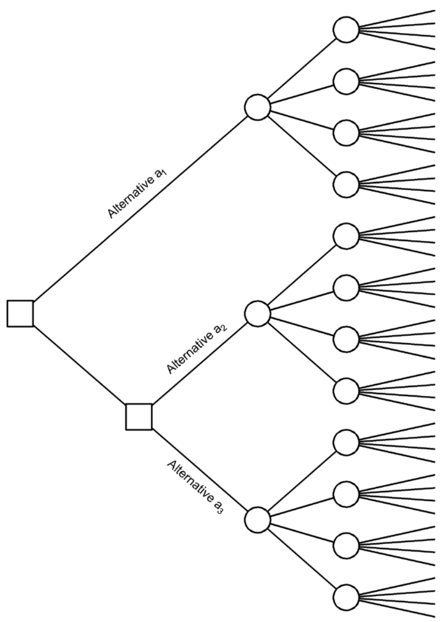

***Figure 3.** Decision tree established for the empirical study*

Although freight rate is agreed upon by the contracting parties through performing a comprehensive financial analysis taking into consideration cargo, transportation mode, distance, and handling capabilities of ports, this rate is assumed as being highly influenced by local, regional, and global political or economic factors, transportation demand, and financial situation, especially while the determination of freight rate profit margin. Hence Baltic dry index (BDI) is a useful source while calculating the margin. BDI is described as average daily freight rates from member shipowners chartering ships traveling across different sea routes carrying various dry bulk cargoes [30]. BDI is published by the Baltic exchange located in London. BDI is also a significant reference indicating useful knowledge concerning global dry bulk shipping. BDI and global trade are consequently directly proportional [31]. Sixty months

***Table 2.** Ship data and alternatives for empirical study [27,28]*

	a_1	a_2		a_3		
Ship designation	**Existing ship**	**Ship no: 1**	**Ship no: 2**	**Ship no: 3**	**Ship no: 4**	**Ship no: 5**
Deadweight (tons)	171,900	73,630	73,630	52,050	32,083	73,630
Gross tonnage (tons)	88,000	40,230	40,230	29,407	19,730	40,230
Cargo capacity (m^3)	187,000	90,624	90,624	65,181	40,656	90,624
Speed (knots)	15.1	14.4	14.4	14.7	14	14.4
Estimated value (in million $)	24	12	12	7.5	4.5	12
Fuel oil consumption (tons/day)	58.3	38.45	38.45	27.6	23.7	38.45
Diesel oil consumption (tons/day)	4.5	2.5	2.5	1.7	1.2	2.5
Gear consumption (tons/day)	0	0	0	2	2	0
Daily running costs	$6,600	$5,200	$5,200	$4,800	$4,300	$5,200
Load port expenses	$73,000	$55,000	$55,000	$40,000	$23,000	$55,000
Discharge port expenses	$68,000	$52,000	$52,000	$38,500	$21,500	$52,000
Other expenses	$5,500	$4,000	$4,000	$3,000	$2,500	$4,000

***Table 3.** Fuel oil price probabilities [29]*

IFO380 interval	Average value of IFO380 interval	Probability %
$200-$300	$251	23%
$300-$400	$357	36%
$400-$500	$433	38%
$500-$600	$508	3%

of BDI statistics are deemed satisfactory to reflect of status-quo in bulk trading for the context of the study and considered probabilities in Table 4 [32]. BDI interval values are determined considering the minimum and maximum values of the statistics in Table 4.

Table 4. *Probabilities of BDI intervals [32]*

BDI interval	Probability %
0-625	16%
625-1,250	48%
1,250-1,875	31%
1,875-2,500	5%
BDI: Baltic dry index	

3.3. Voyage Estimation

Voyage estimation is the budgetary calculation performed to acquire the return of a voyage by subtracting the total expenses of the voyage from gross income. The terms and conditions regulating the relevance between the charterer and the shipowner are prescribed in an agreement called charter party [33]. Freight rate determined based on a voyage estimation and agreed upon by the parties is also given in the charter party [13]. Even non-profitable agreements could be signed for specific reasons like having the ship loaded while being navigated to subsequent profitable cargo locations or for dry-docking purposes etc. [15]. A basic voyage estimation for a merchant vessel could be carried out via formulation given between Equations (7) and (22) below. Voyage estimation is performed within the context of this study to obtain payoff values of each consequence of alternatives given in the decision-making problem stated in the empirical study and adhere to the assumptions given below.

W_C = Cargo capacity, tons, refer to Equation (7).

S_C = Cargo capacity, m^3, refer to Table 2.

ρ = Cargo density, taken as 577 tons/m^3 for grain [34].

W_B = Bulk cargo, tons, refer to Equation (8).

%U = Cargo capacity utilization ratio (i.e., taken as 0.9 as per envisaged by statistical analysis of ship data).

T_{SEA} = Duration of voyage at sea, days, refer to Equation (9).

X_L = Laden distance, nautical miles (i.e., X_L is the distance between departure and arrival ports. It is assumed that the shipowner would trade distance of 3,583 miles between Port Hedland, Australia, and Lianyungang, China [35]).

X_B = Ballast distance, nautical miles (i.e., X_B is the distance traveled without cargo, on ballast condition. Assumed as 950 nautical miles as envisaged by statistical analysis of ship data).

V_S = Speed of the ship, knots, refer to Table 2.

T_{PORT} = Duration of voyage at port, days, refer to Equation (10).

H_D = Departure port cargo handling capacity, assumed as 40,000 tons/day for Port Hedland, Australia [36].

H_A = Arrival port cargo handling capacity, assumed as 15,000 tons/day for Lianyungang, China [36].

T = Total duration of the voyage, days, refer to Equation (11).

FR_B = Breakeven freight, USD ($) (i.e., FR_B is the freight rate just compensating the costs of charter, zero-profit point), refer to Equation (12).

$D_{R/C}$ = Daily running cost, USD ($), refer to Table 2.

C_{BULK} = Bulk Cargo, tons.

%C = Commission (%), assumed as 3% as obtained by statistical analysis of ship data.

%FR = Freight tax (%) (No freight tax is envisaged).

FR = Freight rate, USD ($), refer to Equation (13).

$\%K_P$ = Freight rate profit margin (%), as obtained by statistical analysis of ship data, refer to Table 5.

E_P = Total port expenses, USD ($), refer to Equation (14).

E_L = Load port expenses, USD ($), refer to Table 2.

E_D = Discharge port expenses, USD ($), refer to Table 2.

E_C = Canal expenses, USD ($) (No canal expense is envisaged).

E_O = Other expenses, USD ($), refer to Table 2.

E_B = Bunker costs, USD ($), refer to Equation (15).

$P_{F/O}$ = Fuel oil price, USD ($), refer to Table 3.

$P_{D/O}$ = Diesel oil price, USD ($), taken as $550 that is the average of the last forty months.

$FC_{F/O}$ = Fuel oil consumption, tons/day, refer to Table 2.

FC_G = Gear consumption, tons/day, refer to Table 2.

$FC_{D/O}$ = Diesel oil consumption, tons/day, refer to Table 2.

E_{CM} = Commission expenses, USD ($), refer to Equation (16).

E_{FT} = Freight tax expenses, USD ($), refer to Equation (17).

E_T = Total expenses, USD ($), refer to Equation (18).

R_G = Gross revenue, USD ($), refer to Equation (19).

R_N = Net revenue, USD ($), refer to Equation (20).

$D_{T/C}$ = Daily time charter rate, USD ($), refer to Equation (21).

$D_{N/P}$ = Daily net profit, USD ($), refer to Equation (22).

Table 5. *Assumed freight rate profit margin, %K_P*

BDI interval	Freight rate profit margin, %K_P
0-625	80%
625-1,250	107%
1,250-1,875	118%
1,875-2,500	125%
BDI: Baltic dry index	

$$W_C = S_C \times \quad (7)$$

$$W_B = W_C \times \%U \quad (8)$$

$$T_{SEA} = \frac{(X_L + X_B)}{(V_S \times 24)} \quad (9)$$

$$T_{PORT} = \left(\frac{W_B}{H_D}\right) + \left(\frac{W_B}{H_A}\right) \quad (10)$$

$$T = T_{SEA} + T_{PORT} \quad (11)$$

$$FR_B = \frac{\left(E_B + E_P + (D_{R/C} \times T)\right)}{\left((C_{BULK} \times (1 - \%C)) - \%FR\right)} \quad (12)$$

$$FR = FR_B \times \% K_P \quad (13)$$

$$E_P = E_L + E_D + E_C + E_O \quad (14)$$

$$E_B = (T_{SEA} \times FC_{F/O} \times P_{F/O}) + (T \times FC_{D/O} \times P_{D/O}) + (T_{PORT} \times FC_G \times P_{D/O}) - \left[\frac{X_B}{(V_S \times FC_{F/O})}\right] \times FC_{F/O} \times P_{F/O} \quad (15)$$

$$E_{CM} = R_G \times \%C \quad (16)$$

$$E_{FT} = R_G \times \%FR \quad (17)$$

$$E_T = E_B + E_{CM} + E_P + E_{FT} \quad (18)$$

$$R_G = (\%FR \times W_B) \quad (19)$$

$$R_N = R_G - E_T \quad (20)$$

$$D_{T/C} = \frac{R_N}{X_L} \quad (21)$$

$$D_{N/P} = D_{T/C} - D_{R/C} \quad (22)$$

3.4. Application of Expected Value Method and Cumulative Prospect Theory

There are forty-eight combinations (i.e., consequences) in the empirical study as calculated according to Equation (23), where n_i, n_A, $n_{F/O,}$ and n_{BDI} represents several consequences, alternatives, fuel oil price probabilities as given in Table 3, and probabilities of freight rate profit margin as indicated in Tables 4 and 5.

$$n_i = n_A \times n_{F/O} \times n_{BDI} \quad (23)$$

Daily net profit, $D_{N/P}$ of the consequences (i.e., payoff values) are indicated by column "a_i" of Tables 6-8 for $a_{1,}$ $a_{2,}$ a_3, respectively. Outcomes are ordered from the lowest outcome positioned at the top and highest at the bottom of the tables to comply with the CPT methodology [8]. Probabilities of these outcomes are also arranged according to the rank of outcomes. The column "$v(a_i)$" in the tables represents the prospect value of these outcomes as per Equation (5). Probabilities described in Tables 3 and 4 are presented by the columns "p(IFO)" and "p(BDI)," respectively. The column "p_i" is the multiplication of p(IFO) and p(BDI) to yield probabilities of consequences where p(BDI) and p(IFO) are considered independent. The probabilities of p_i are cumulated from top to bottom for losses and from bottom to top for gains and stated in the column "Cumul." [8]. Cumulated probabilities are transformed as per Equation (6), given in the column "Transf." and decumulated analogously to the way they are cumulated. Multiplication of decumulated probabilities in the column "Decum." and values shown by the column "$v(a_i)$" are called CPT values and given in the column "CPT" of the tables. The sum of all CPT values of consequences of an alternative is given in the row "CPT(a)." Expected values of the consequences are also calculated. The values in the column "a_i" are multiplied by the values in the column "p_i" according to the expected value approach as per Equation (1), and the obtained value is entered into the column "$EV(a_i)$." Sum of these values is mentioned in the row "EV(a)."

Two-digit accuracy is deemed sufficient for presenting the results where thirteen-digit accuracy is used during calculations.

3.5. Result of the Empirical Study

Prescriptive and descriptive analyses conducted for alternatives are respectively shown in Figure 4 and Figure 5. These figures are a continuation of the decision tree given in Figure 3. Different results are obtained via the expected value approach and CPT as calculated by two-part power function as shown in Equations (5) and (6).

Table 6. *CPT and EV calculation of the alternative a_1*

i	a_i	$v(a_i)$	p(BDI)	p(IFO)	p_i	*Cumul.*	*Transf.*	*Decum.*	CPT	$EV(a_i)$
-4	-$6,496	-5,097	16%	3%	0.48%	0.48%	2.57%	2.57%	-131	-$31
-3	-$6,004	-4,756	16%	38%	6.08%	6.56%	13.43%	10.86%	-517	-$365
-2	-$5,499	-4,402	16%	36%	5.76%	12.32%	19.48%	6.05%	-267	-$317
-1	-$4,805	-3,910	16%	23%	3.68%	16.00%	22.67%	3.19%	-125	-$177
1	$1,682	690	48%	23%	11.04%	84.00%	64.38%	9.01%	63	$186
2	$1,925	777	48%	36%	17.28%	72.96%	55.38%	10.34%	81	$333
3	$2,102	840	48%	38%	18.24%	55.68%	45.04%	9.33%	79	$383
4	$2,274	900	48%	3%	1.44%	37.44%	35.71%	0.73%	7	$33
5	$4,325	1,584	31%	23%	7.13%	36.00%	34.98%	3.75%	60	$308
6	$4,949	1,784	31%	36%	11.16%	28.87%	31.23%	6.64%	119	$552
7	$5,404	1,927	31%	38%	11.78%	17.71%	24.59%	10.23%	198	$637
8	$5,847	2,065	31%	3%	0.93%	5.93%	14.36%	1.19%	25	$54
9	$6,006	2,115	5%	23%	1.15%	5.00%	13.17%	1.67%	36	$69
10	$6,874	2,381	5%	36%	1.80%	3.85%	11.50%	3.28%	79	$124
11	$7,505	2,573	5%	38%	1.90%	2.05%	8.22%	6.38%	165	$143
12	$8,120	2,757	5%	3%	0.15%	0.15%	1.84%	1.84%	51	$12
EV(a)=$1,944										
CPT(a)=-77										
EV: Enterprise value, CPT: Cumulative prospect theory, BDI: Baltic dry index										

Table 7. *CPT and EV calculation of the alternative a_2*

i	a_i	$v(a_i)$	p(BDI)	p(IFO)	p_i	Cumul.	Transf.	Decum.	CPT	$EV(a_i)$
-4	-$10,732	-7,929	16%	3%	0.48%	0.48%	2.57%	2.57%	-204	-$52
-3	-$9,903	-7,387	16%	38%	6.08%	6.56%	13.43%	10.86%	-803	-$602
-2	-$9,053	-6,826	16%	36%	5.76%	12.32%	19.48%	6.05%	-413	-$521
-1	-$7,883	-6,044	16%	23%	3.68%	16.00%	22.67%	3.19%	-193	-$290
1	$2,759	1,067	48%	23%	11.04%	84.00%	64.38%	9.01%	97	$305
2	$3,169	1,205	48%	36%	17.28%	72.96%	55.38%	10.34%	125	$548
3	$3,466	1,304	48%	38%	18.24%	55.68%	45.04%	9.33%	122	$632
4	$3,757	1,400	48%	3%	1.44%	37.44%	35.71%	0.73%	11	$54
5	$7,095	2,449	31%	23%	7.13%	36.00%	34.98%	3.75%	92	$506
6	$8,147	2,765	31%	36%	11.16%	28.87%	31.23%	6.64%	184	$909
7	$8,913	2,993	31%	38%	11.78%	17.71%	24.59%	10.23%	307	$1,050
8	$9,659	3,212	31%	3%	0.93%	5.93%	14.36%	1.19%	39	$90
9	$9,853	3,269	5%	23%	1.15%	5.00%	13.17%	1.67%	55	$113
10	$11,316	3,692	5%	36%	1.80%	3.85%	11.50%	3.28%	122	$204
11	$12,378	3,996	5%	38%	1.90%	2.05%	8.22%	6.38%	255	$235
12	$13,415	4,289	5%	3%	0.15%	0.15%	1.84%	1.84%	79	$20
EV(a)=$3,201										
CPT(a)=-125										
EV: Enterprise value, CPT: Cumulative prospect theory, BDI: Baltic dry index										

Table 8. *CPT and EV calculation of the alternative a_3*

i	a_i	$v(a_i)$	p(BDI)	p(IFO)	p_i	Cumul.	Transf.	Decum.	CPT	$EV(a_i)$
-4	-$13,314	-9,585	16%	3%	0.48%	0.48%	2.57%	2.57%	-247	-$64
-3	-$12,286	-8,931	16%	38%	6.08%	6.56%	13.43%	10.86%	-970	-$747
-2	-$11,232	-8,253	16%	36%	5.76%	12.32%	19.48%	6.05%	-500	-$647
-1	-$9,782	-7,308	16%	23%	3.68%	16.00%	22.67%	3.19%	-234	-$360
1	$3,424	1,290	48%	23%	11.04%	84.00%	64.38%	9.01%	117	$378
2	$3,932	1,457	48%	36%	17.28%	72.96%	55.38%	10.34%	151	$679
3	$4,300	1,576	48%	38%	18.24%	55.68%	45.04%	9.33%	148	$784
4	$4,660	1,692	48%	3%	1.44%	37.44%	35.71%	0.73%	13	$67
5	$8,804	2,961	31%	23%	7.13%	36.00%	34.98%	3.75%	112	$628
6	$10,109	3,344	31%	36%	11.16%	28.87%	31.23%	6.64%	223	$1,128
7	$11,057	3,618	31%	38%	11.78%	17.71%	24.59%	10.23%	371	$1,303
8	$11,983	3,883	31%	3%	0.93%	5.93%	14.36%	1.19%	47	$111
9	$12,228	3,953	5%	23%	1.15%	5.00%	13.17%	1.67%	67	$141
10	$14,040	4,464	5%	36%	1.80%	3.85%	11.50%	3.28%	147	$253
11	$15,357	4,831	5%	38%	1.90%	2.05%	8.22%	6.38%	309	$292
12	$16,642	5,184	5%	3%	0.15%	0.15%	1.84%	1.84%	96	$25
EV(a)=$3,971										
CPT(a)=-150										
EV: Enterprise value, CPT: Cumulative prospect theory, BDI: Baltic dry index										

Former reveals expected values of alternatives as $3,971>$3,201>$1,944, indicating preference of prescriptive approach as $a_3>a_2>a_1$ where latter yields the CPT values of alternatives as -77>-125>-150 representing preference of descriptive approach as $a_1>a_2>a_3$. Different sequences of alternatives obtained via the expected value method and CPT are far from being unexpected and could theoretically be explained by the fact that the latter considers the human perception of value and risk aversive nature, while the former lacks to include the human sense of risk aversion and favors the alternative with the highest outcome. More excitingly, this study and its result could excellently be referred to uncover human sense behind the current situation in maritime bulk trading that high demand for capesize [i.e., large bulk carriers between 110,000 and 200,000 deadweight tonnage (DWT)] under uncertain pandemic conditions led BDI to its peak of a 13-year period despite the losses recorded in panamax (i.e., bulk carriers smaller than capesize of 80,000-110,000 DWT) and handysize (i.e., small bulk carriers between 10,000-40,000 DWT) [37-39].

4. Implications and Conclusion

Maritime trading is perceived as the easiest way to transport commodities in high volume through long distances and as a profitable business for maritime traders, shipowners, and related parties. However, it is vulnerable to uncertainties, namely global financial status, political or economic incidents, rate of production, and demand for transportation.

Individuals make decisions for institutions with bounded rationalities under uncertain conditions. Managerial decision-making processes heavily depend on a manager or an executive's intuition and are regarded as swift to solve problems practically. Formal decision-making introduces systematic methods for decision-making that are often required to handle more complex issues, advocate against others, or reconcile related parties despite being judged as effortful and complicated. Formal decision-making is usually executed through prescriptive or descriptive approaches. Expected value method and expected utility theory are prescriptive whereas prospect theory and CPT are descriptive approaches. It is disputable to judge whether prescriptive or descriptive approach is better than the other, yet it could be estimated that descriptive approaches are more advanced in reflecting human behavior.

Although researchers in the literature broadly examine decision-making for maritime trading and ship sale and purchase activities using methods such as NPV, ROA, AHP, and fuzzy analysis, there is a need for an academic contribution to be provided by conducting a study based on a descriptive method representing human attitude toward risky situations, perception of the value of gain and loss,

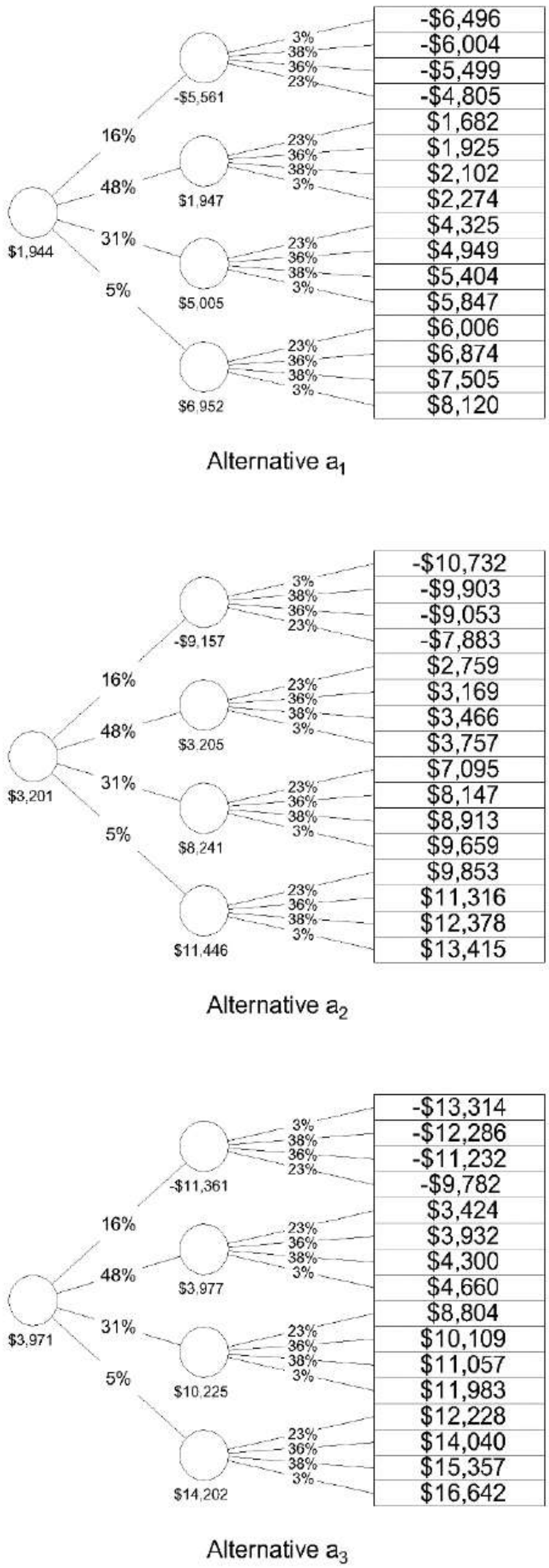

Figure 4. *Expected values of alternatives*

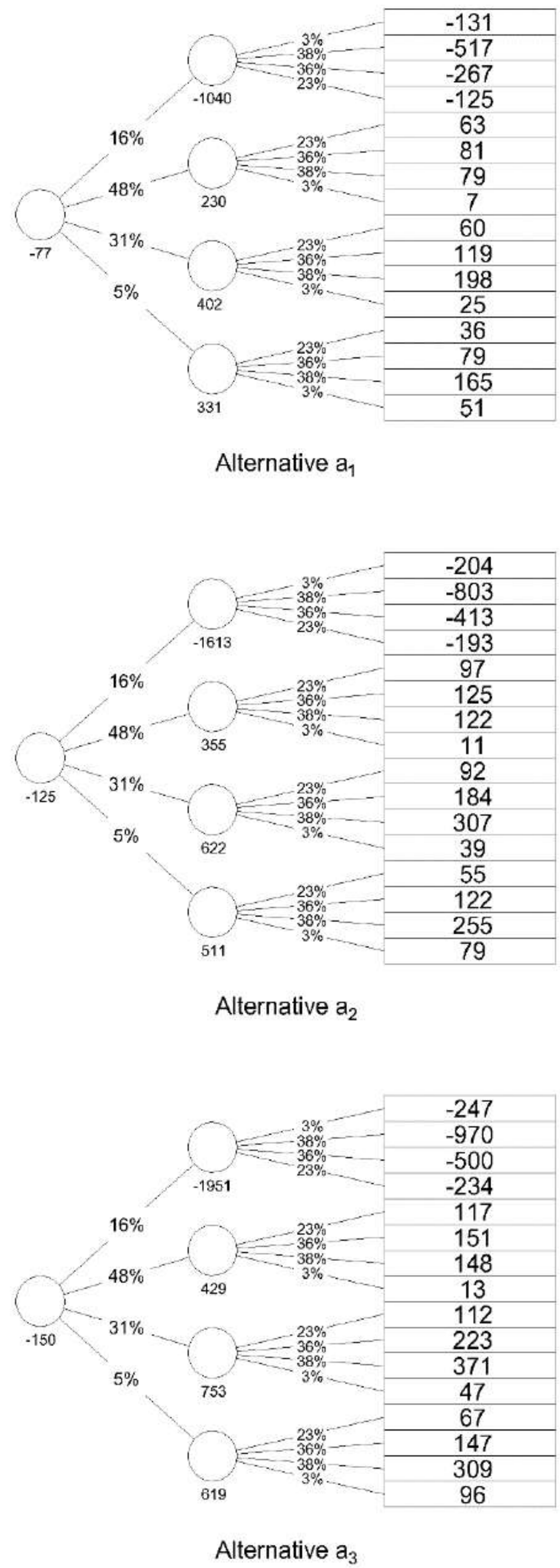

Figure 5. *CPT values of alternatives*

CPT: Cumulative prospect theory

and different meanings of probabilities could not be left unanswered. This research contributes to the enriched academic literature by explaining the human perception of value and risks underlying existing conditions of ship sale and purchase activities using a descriptive formal decision-making method by CPT. The descriptive result obtained via this study under prescribed assumptions revealed that trading with larger ships would seem by common human risk aversive nature more preferable than to sell the existing ship, purchase and trade with smaller ones especially considering uncertainty factors affecting maritime trading. This valuable finding is also supported via evidence provided in the results of the empirical study by referring to the preference of capesize against handysize bulk carriers as obtained from examining the current situation of maritime trading.

There are limitations of this study. First, it is concerned with uncertainty factors. States of nature include uncertainty of fuel oil price and freight rate profit margin that is considered highly related with the BDI and keeping any other parameters constant for ease of calculation. It is recommended to extend the scope of this work by defining other relevant uncertainties like shipowners' financial status, fluctuations in the commercial fleet, local, regional and global production, trading capacity, and cargo transportation demand in addition to fuel price and freight rate profit margin. Sub-indices related to BDI could further be considered for obtaining more accurate results. Second, it is advisable for enthusiastic researchers interested in the study to perform questionnaires or surveys on professionals involved in ship sale and purchase decision-making processes to strengthen the results obtained via formal decision-making methods. Finally, researchers are urged to apply CPT by empirical two-part power value function and enrich the analysis by data obtained from such questionnaires.

Authorship Contributions

Concept design: A. Güngör, Data Collection or Processing: A. Güngör, B. Barlas, Analysis or Interpretation: A. Güngör, B. Barlas, Literature Review: A. Güngör, Writing, Reviewing and Editing: A. Güngör, B. Barlas.

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Performance and Reliability Monitoring of Ship Hybrid Power Plants

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Abstract

Recently, the marine industry has been under a paradigm shift toward adopting increased automation, and initiatives to enable the autonomous operations of ships are ongoing. In these cases, power plants require advanced monitoring techniques not only for the performance parameters but also to assess the health state of their critical components. In this respect, this study aims to develop a monitoring functionality for power plants that captures the performance metrics while considering the overall system and its components' reliability. A hybrid power plant of a pilot boat is considered a case study. A rule-based energy management strategy is adopted, which makes the decisions on the power distribution to the investigated power plant components. Additionally, a dynamic Bayesian network is developed to capture the temporal behavior of the system's/components' reliability accounting for the power plant's operating profile. Results demonstrate that the selected hybrid power plant monitoring capabilities are enhanced by providing the power plant performance along with the estimation of the system's health state. Furthermore, these extended monitoring capabilities can provide the essential metrics to facilitate decisionmaking, enabling the autonomous operation of the power plant.

Keywords: Hybrid power plant, Monitoring, Energy management, Dynamic Bayesian network, Autonomous operations

1. Introduction

As technological breakthroughs have been maturing, modern vessels incorporate smart technologies capable of performing various automated tasks [1]. Adopting smart sensors and systems onboard ships enables increased monitoring capabilities, which is crucial for next-generation autonomous ships to perform autonomous decision-making actions. Several research projects have been investigating and developing technologies to enable autonomous shipping. Specifically, AUTOSHIP has been focused on developing and applying key enabling technologies in two autonomous ships, highlighting the importance of autonomous machinery systems with predictive condition monitoring capabilities [2]. Furthermore, MUNIN provided a concept for an autonomous ship, pinpointing the importance of an intelligent machinery system that can perform monitoring tasks with advanced failure predetection and handling functionalities [3].

The power plant operation of modern ships is already highly automated. Sensors are installed to monitor the performance of the majority of the power plant components. Usually, the acquired data are pertinent to performance measurements, including fuel consumption and emissions [4]. Nevertheless, smart ships require extended monitoring capabilities to assess the health state of their power plants.

In this respect, traditional metrics or key performance indicators are insufficient to capture the plant's health state. Data from sensors can enable diagnostic functionalities in the power plant while also being employed to estimate the health state and determine the remaining useful life (RUL) of the investigated components or system [5]. Automotive and aerospace industries already employ several methods to estimate the health state and perform future predictions using the prognostics and health management framework [6]. However, the maritime industry lags in terms of using similar methods. Gkerekos et al. [7] proposed an approach

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to monitor the machinery's health state using vibration data. Lazakis et al. [8] used a dynamic time series neural network to predict future operating values of ship machinery critical systems. Using a similar approach, Zaman et al. [9] applied a condition monitoring approach using neural networks on the main engine to predict future variations of performance parameters while combining reliability tools for criticality assessment. In Kökkülünk et al. [10], a mathematical model to estimate engine degradation was developed under varying operating conditions. Nevertheless, the aforementioned studies typically focused on calculating the health state of a particular component or individual system without incorporating insight into the power plant as an integrated system.

Moreover, for the successful operation of unmanned missions, Edge et al. [11] argued that priority should be given to the selection and optimization of the machinery design in respect to the availability. Pertinent literature reports attempted to monitor autonomous power plants operations. Abaei et al. [12] developed a probability model based on the multinomial process tree and hierarchical Bayesian model to evaluate the reliability of an unattended machinery plant under the influence of random events. Ellefsen et al. [13] acknowledged the potential of using deep learning techniques to estimate the RUL of autonomous systems in real time from measured shipboard data. Bolbot et al. [14] introduced the concept of a safety monitoring system in cruise ship power plants to estimate the probability of blackout using sensor measurements. Utne et al. [15] highlighted the importance of dynamic risk monitoring and control in autonomous marine systems, although these tools have not been currently implemented in the maritime sector.

From the preceding studies, the following research gaps are identified: (a) a systematic and structured framework to monitor the machinery health state in the maritime industry is not available, (b) the influence of the performance profile on the health state of the components have not been investigated, and (c) the overall system's dynamic health state estimation based on an actual operational profile has not been addressed.

In this respect, this study aims to develop a monitoring functionality for power plants that captures performance metrics while considering the overall system and its components' reliability as health indicators. Modeling of the power plant's performance is done using a combination of the first principles method, look-up tables, and built-in Simulink blocks. The reliability of the power plant's components is calculated using failure rates based on the proportional hazard model (PHM), while the system's reliability is calculated using a dynamic Bayesian network (DBN). A parallel hybrid power plant of a pilot boat is selected as a case study.

2. Methodology Overview

The methodological steps to develop the monitoring functionality are presented herein. The first step is to develop a rule-based energy management strategy that defines the operating setpoints for the power plant components. Subsequently, performance models are employed to estimate the power plant's behavior. In the next step, the power plant's operating points are fed into the PHM to update the failure rate and calculate the components' reliability. Finally, using the components' reliability, the system reliability is calculated using the DBN.

3. System Description & Performance Modeling

In this study, a parallel hybrid power plant of a pilot boat is selected to demonstrate the proposed methodology's applicability. Figure 1 shows a schematic representation of the power plant's configuration. The hybrid power plant is a combination of a diesel engine, a battery, and an electric machine. The diesel engine and the electric machine are coupled via a gearbox. The electric machine can be used as a power take in (PTI) to supply propulsive power and as a power take off (PTO) to charge the battery. Table 1 presents the power plant's components' characteristics.

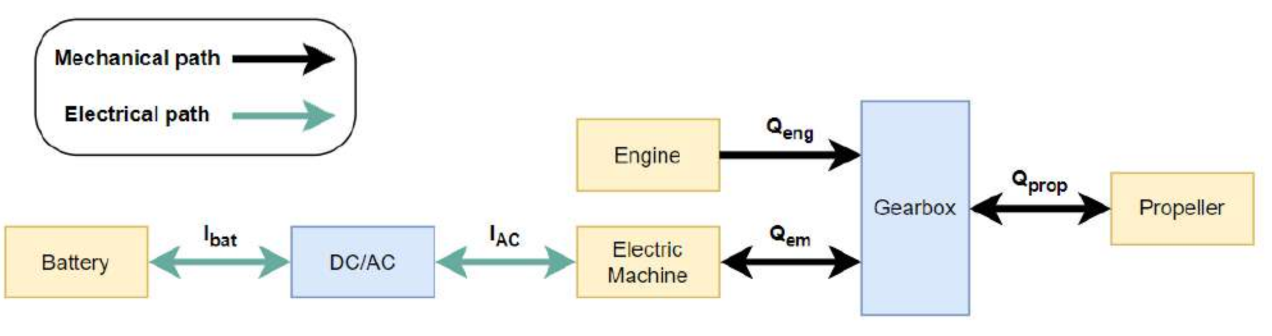

Figure 1. *Parallel hybrid power plant configuration*

Table 1. *Component's characteristics*

Component	Parameter	Value
Engine	Type	4 stroke, 8 cylinders
	Power MCR (kW)	423
	Speed MCR (RPM)	2100
Electric machine	Nominal power (kW)	100
Battery	Type	Lithium ion
	Module capacity (Ah)	100
	Nominal voltage (V)	12
	Number of modules	100
MCR: Maximum continuous rating		

The investigated hybrid power plant is modeled in MATLAB/Simulink environment using a modular approach. Each power plant component is modeled as a separate block, and connections facilitate the parameters' exchange between the interconnected components.

3.1. Diesel Engine Modeling

The performance of the diesel engine is modeled by employing the mean value engine model proposed by Theotokatos [16]. The engine brake mean effective pressure is calculated by subtracting the friction mean effective pressure (FMEP) from the indicated mean effective pressure (IMEP). The FMEP is considered a function of the IMEP and the engine crankshaft rotation speed, whereas the IMEP is calculated using the rack position, the maximum IMEP, and the combustion efficiency.

The torque produced by the engine is calculated using the following equation:

$$Q_{eng} = \frac{BMEP\, V_D}{2\pi\, rev_{cy}} \tag{1}$$

where rev_{cy} is the number of crankshaft revolutions per cycle.

The engine fuel mass flow rate is calculated as:

$$\dot{m}_f = \frac{z_{cyl}\, m_{f,cy}\, N_{eng}}{60\, rev_{cy}} \tag{2}$$

where z_{cyl} denotes the cylinder number and $m_{f,cy}$ is the mass of injected fuel per cylinder per cycle, the variation of which versus the engine rack position is provided as input.

The following equations are employed to calculate the engine brake power and brake specific fuel consumption (BSFC):

$$P_b = \frac{\pi\, N_{eng}\, Q_{eng}}{30} \tag{3}$$

$$BSFC = \frac{\dot{m}_f}{P_b} \tag{4}$$

The engine governor is modeled using a proportional-integral (PI) controller law [16].

3.2. Electric Machine Modeling

For the modeling of the electric machine, a quasi-static approach is followed, which is widely used in supervisory automotive control applications [17,18]. Energy losses are calculated based on the operating point of the electric machine [19]. The power output is then expressed as:

$$P_{em} = \frac{1}{\eta_{em}\left(N_{em}, P_{elec}\right)} \frac{\pi N_{em}\, Q_{em}}{30}, \quad P_{elec} \geq 0 \ (\textit{Motor Mode}) \tag{5}$$

$$P_{em} = \eta_{em}\left(N_{em}, P_{elec}\right) \frac{\pi N_{em}\, Q_{em}}{30}, \quad P_{elec} < 0 \ (\textit{Generator Mode}) \tag{6}$$

where η_{em} is the efficiency of the electric machine, which is considered a function of its speed and electric power.

The desired power output of the electric machine is controlled using a similar (PI) controller approach as in the case of the diesel engine.

3.3. Battery

The power plant battery is considered to be of the lithiumion type with 100 modules. To model the battery's behavior while charging and discharging, the built-in simscape model proposed by Tremblay and Dessaint [20] was employed. Specifically, the battery's voltage in discharge and charge is respectively obtained by the following equations:

$$V_{bat} = E_0 - R\, i - K \frac{Q}{Q - i\,t}\left(it + i^*\right) + A exp(-B\, it),$$
$$i^* > 0 \left(Discharge\right) \tag{7}$$

$$V_{bat} = E_0 - R\, i - K \frac{Q}{it - 0.1\, Q}\, i^* - K \frac{Q}{Q - it}\, it + A exp(-B\, it),$$
$$i^* < 0 \ (Charge) \tag{8}$$

where V_{bat} is the battery voltage, E_0 is the battery constant voltage, K is a polarization constant, Q is the battery capacity corresponding to the actual battery charge, A is the exponential zone amplitude, B is the exponential zone time constant inverse, R is the internal resistance, it is the actual battery charge ($\int idt$), i is battery current, and i^* denotes the filtered current.

3.4. Gearbox

The following equation derived from angular momentum conservation in the gearbox is used to calculate the engine speed:

$$\frac{dN_{eng}}{dt} = \frac{30\left(\eta_{gb}\left(Q_{eng} - Q_{em}\right) - Q_{prop}\right)}{\pi\left(I_{eng} + I_{em} + I_{gb} + I_{prop}\right)} \tag{9}$$

where η_{gb} denotes the gearbox efficiency and I_{eng}, I_{gb}, I_{em}, and I_{prop} are the polar moments of the inertia of the engine, electric machine, gearbox, and propeller, respectively.

3.5. Propeller

Finally, the propeller law is utilized to calculate the propeller toque. To calculate the constant parameter k_p, the engine torque and speed at the maximum continuous rating (MCR) are used. As a result, the propeller torque is expressed as:

$$Q_{prop} = k_p N_{eng}^2 \quad (10)$$

4. Rule-based Energy Management

Since the power plant consists of a parallel hybrid configuration, a supervisory control strategy must be adopted to allocate the load to various power sources [21]. This study adopts a rule-based energy management strategy (RB-EMS) to specify the operating mode (e.g., hybrid and electric) and the components' operating point. This strategy is implemented using the Stateflow state machine in Simulink, which can be used to develop a decision logic and supervisory control strategies for hybrid systems [22].

The power plant can switch between different modes including hybrid, fully electric, and mechanical. Similar approaches have been presented in the pertinent literature [23,24]. Table 2 presents the decision logic. It must be noted that the mechanical mode is included in the hybrid mode with the electric machine switched off.

Table 2. *Rule-based energy management strategy*

	State of charge		
Requested engine speed (rev/min)	0-40	40-80	80-100
0-1000	Hybrid	Electric	Electric
1000-1400	Hybrid	Hybrid	Electric
1400-2100	Hybrid	Hybrid	Electric
The mechanical mode is included in the hybrid mode with the electric machine switched off			

After the operating mode is defined, the operating point of every component is specified. When the engine is switched on, it is set to operate at the optimal (BSFC) point in the current engine speed. In case of surplus power, it is used to charge the battery and the electric machine operates in the PTO mode. In contrast, when the engine load is not sufficient to satisfy the propeller demand, the electric machine is used in the PTI mode.

5. Reliability Modeling

5.1. Dynamic Bayesian Networks

To capture the health state of the investigated system and its components, reliability is used as a metric to demonstrate degradation. Mathematically, reliability is defined as the probability that a component is functioning at the time interval (0,t), where t is the mission time [25]. As a result, reliability can be used as an alternative to describing the degradation function [26].

In this study, a DBN approach is used. DBNs are an extension of the conventional Bayesian network (BN) that can capture the temporal behavior of the network, as they can predict future node probabilities based on the feeding evidence [27].

A BN is a pair of a directed acyclic graph (DAG) and a joint probability distribution function that satisfies the Markov condition [28]. The DAG is defined by nodes (V) and edges (E) where nodes are random variables and edges show the probabilistic relationships between the nodes.

The BN consists of the qualitative part, where the topology of the network is represented by the DAG, and the quantitative part, where conditional probabilities are specified to make the numerical inference [29]. The joint probability distribution function of the network is calculated as the product of all conditional probability density functions of each node given all its parent nodes as follows [30]:

$$P\left(X_1, X_2, \ldots, X_n\right) = \prod_{i=1}^{n} P\left(X_i \mid Pa\left(X_i\right)\right) \quad (11)$$

where $Pa(X_i)$ represents the parent set of variable X_i and $P(X_i|Pa(X_i))$ is the conditional probability distribution function of variable X_i given its parent set.

The limitation of the conventional BN is its inability to capture temporal relationships between the nodes of the network, resulting in a static representation of the joint probability distribution function at a specific time instant [28]. To overcome this limitation, DBN were introduced, which can provide temporal dependencies of network nodes considering the previous time slice. The joint probability distribution function of the DBN network from the previous time slice to the current time slice can be expressed as [27]:

$$P(Z_t \mid Z_{t-1}) = \prod_{i=1}^{n} P\left(Z_{i,t} \mid Pa\left(Z_{i,t}\right)\right) \quad (12)$$

where Z is the family of random variables $X_1, X_2, \ldots, X_N$, $Z_{i,t}$ is the ith node at the time slice t, and $Pa(Z_{i,t})$ is the parent nodes of $Z_{i,t}$ from the same and previous time slices.

Finally, the following equation is employed to calculate the overall joint probability distribution function of the DBN from the first time slice till slice N:

$$P\left(Z_{1:N}\right) = \prod_{t=1}^{N}\prod_{i=1}^{n} P\left(Z_{i,t} \mid Pa\left(Z_{i,t}\right)\right) \quad (13)$$

5.2. Failure Rate Update Model

The failure (or hazard) rate is used to calculate the reliability of the power plant's components. This study considers the operating point (load) of the components as a factor that influences the failure rate. Usually, in health-aware control applications, PHMs are used, which take into account the actuators' control effort in the degradation function [26,31].

The PHM was first introduced by Cox [32] and employs the following expression for the calculation of the failure rate:

$$\lambda\left(t, l\right) = \lambda_0(t) g\left(l, \vartheta\right) \tag{14}$$

where λ_0 is the nominal failure rate dependent on time only and $g(l,\theta)$ is the covariate function that depends on covariate l that affects the component and an unknown parameter θ of the component model. The term $g(l,\theta)$ can take many forms [33]. However, the linear form is considered herein.

In this study, the Weibull PHM (WPHM) proposed by Gorjian et al. [34] is used, which is an extension of the PHM. The failure rate is assumed to follow the Weibull distribution, resulting in an increasing failure rate with time when the shape factor β is greater than one. According to the WPHM, the failure rate is calculated as follows:

$$\lambda\left(t, l\right) = \beta \lambda_0^{\beta} t^{\beta-1} g\left(l, \vartheta\right) \tag{15}$$

Failure rates that are used in this study are based on the OREDA 2015 database [35]. In particular, the components' mean and maximum failure rates are considered. Because the Weibull distribution is followed, a correction procedure for the failure rates is followed according to [36], since the failure rates in the OREDA are assumed constant.

For the diesel engine, it is assumed that the failure rate is the mean of the values provided in the OREDA in the region close to the half load region, whereas it reaches its maximum value in the idle and at full load regions. Consequently, the engine failure rate is calculated by the following equations:

$$\lambda(t, l) = \beta \lambda_{mean}{}^{\beta} t^{\beta-1}\left(\left(\frac{\lambda_{max}}{\lambda_{mean}}\right)^{\beta} + \left(1 - \left(\frac{\lambda_{max}}{\lambda_{mean}}\right)^{\beta}\right)\frac{l}{0.4}\right), \quad 0 \le l < 0.4 \tag{16}$$

$$\lambda(t, l) = \beta \lambda_{mean}{}^{\beta} t^{\beta-1}, \qquad 0.4 \le l < 0.6 \tag{17}$$

$$\lambda(t, l) = \beta \lambda_{mean}{}^{\beta} t^{\beta-1}\left(1 + \left(\left(\frac{\lambda_{max}}{\lambda_{mean}}\right)^{\beta} - 1\right)\frac{l - 0.6}{0.4}\right), \quad 0.6 \le l < 1 \tag{18}$$

For other components, it is assumed that the failure rate is calculated according to Equation (19). The mean failure rate value was considered as reported in the OREDA, whereas it increases as a function of the load till the full load, where it gets its maximum value.

$$\lambda(t, l) = \beta \lambda_{mean}{}^{\beta} t^{\beta-1}\left(1 + \left(\left(\frac{\lambda_{max}}{\lambda_{mean}}\right)^{\beta} - 1\right) l\right) \tag{19}$$

6. Case Study

6.1. Operating Profile

To demonstrate the applicability of the proposed approach, an operating profile that specifies the time variation of the propeller power and speed setpoints is required. Operating data from an actual pilot boat representing the time variation of the engine speed is shown in Figure 2.

Due to the inherent noise of the collected data, this profile was elaborated and was converted into power setpoints for the rule-based energy management strategy. Additionally, the profile corresponding to a one-month operation was developed based on these setpoints and considering a random variation of ±10%. This randomness was included

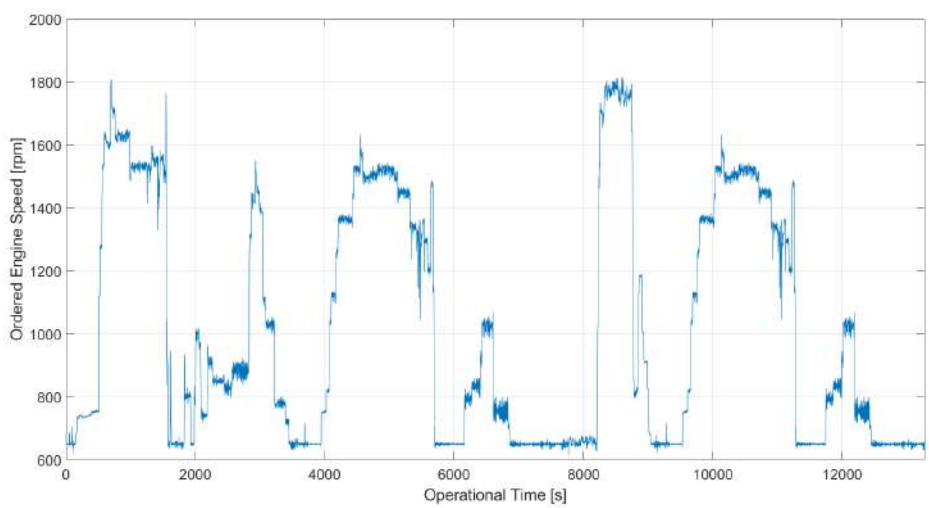

Figure 2. *Actual operating profile of the pilot boat engine case study*

to derive a more realistic scenario. Figure 3 provides the developed operating profile for 6 hours as the one-month operating profile cannot be readily presented in a single plot.

Finally, an overall model screenshot is presented in Figure 4. The model consists of four district subsystems: The operating profile, the rule-based energy management strategy (RB-EMS), the power plant model, and the monitoring subsystem.

6.2. Dynamic Bayesian Network Structure

Figure 5 presents the structure of the developed DBN for the pilot boat power plant case study. Root nodes represent the components of the power plant, while intermediate nodes represent noisy gates. Noisy gates are similar to logical gates of fault trees. It is assumed that the noisy gates are influenced independently by their parent nodes, resulting in a parameter reduction for the corresponding conditional probability tables and a lower computational effort [29].

Since a built-in toolbox to perform the Bayesian inference does not exist in MATLAB libraries, the SMILE engine provided by BayesFusion was used [37]. The engine is written in C++. As a result, a wrapper was used to import the library into MATLAB.

To calculate the reliability of root nodes, the WPHM presented in the preceding sections is used. The reliability of each component is calculated using the following expression:

$$R_i(t) = e^{-\int_0^t \lambda_i(t,l)dt} \quad (20)$$

Root nodes are modeled as unobservable variables in the DBN. However, the components' reliability is calculated directly using equation (20). The SMILE engine supports the use of virtual evidence, where it is allowed to enter uncertain observations (i.e., reliability in this study) into normally unobservable variables [38]. Therefore, the DBN can be updated as the power plant operates at specific time intervals, feeding the root nodes with the components' reliability.

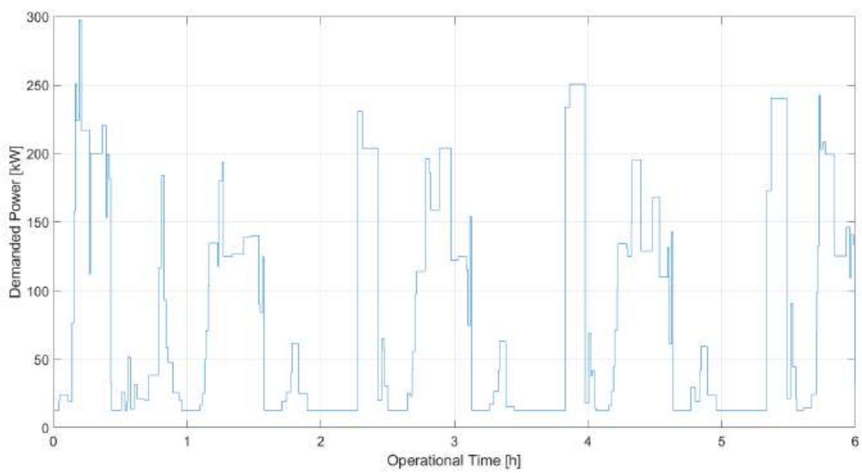

Figure 3. *Sample operating profile for the propeller's power demand of the pilot boat case study*

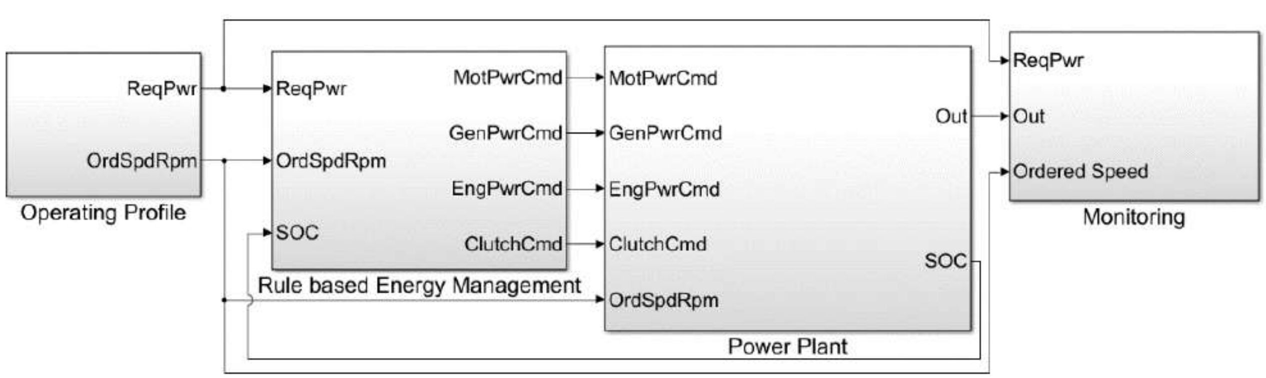

Figure 4. *Screenshot of the overall model in Simulink*

Finally, the shape parameters β of the Weibull distribution for each component are based on relevant experimental studies and their values are presented in Table 3.

Table 3. *Weibull shape parameters*

Component	β	Source
Engine	2.4	[39]
Electric machine	1.2	[40]
Battery	1.69	[41]
Gearbox	2.028	[42]

7. Results and Discussion

In this section, simulation results for the investigated hybrid power plant are presented for a one-month operational time. It must be noted that the operational time is different from the calendar time, as the former only considers the actual time the power plant operates. It was assumed that the components are initially in their healthy state. As a result, their reliability is very close to 1 (slightly less than 1 though).

Figure 6 presents the derived time variations of the components' reliability. Because of the employed time scale, fluctuations of reliability values are not noticeable in this plot; hence, a zoomed region is presented. In particular, the zoomed region presents the engine's reliability between the 28th and 29th operational days. Since the power plant is hybrid, the engine is occasionally switched off according to the rule-based energy management strategy. As a result, there are regions in the graph where the reliability remains constant.

Furthermore, an abrupt decline of the engine's reliability is observed at t=28.3 days, which occurs due to the engine operation in regions close to idle and full loads. Figure 7 presents the power demand and the delivered power by the engine and the electric machine in the region with the abrupt change. Results of this figure confirm that the engine operates close to the idle, which impacts the engine's reliability.

Figure 8 provides the derived time variations of the components' reliability (simulation results) as well as the time variations of the components' reliability calculated taking into account the Weibull distributions with the mean and maximum failure rate values. As observed from this figure, the derived reliability for each component is between the corresponding values calculated using the mean and the maximum failure rates. It must be noted that the engine operating time is around 13 days (instead of 30 days of operational time for other components) due to the engine switching off in several time periods.

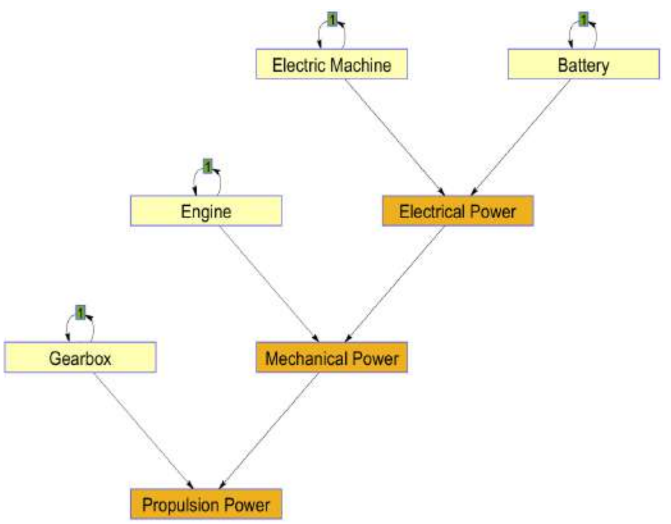

Figure 5. *Developed dynamic Bayesian network structure*

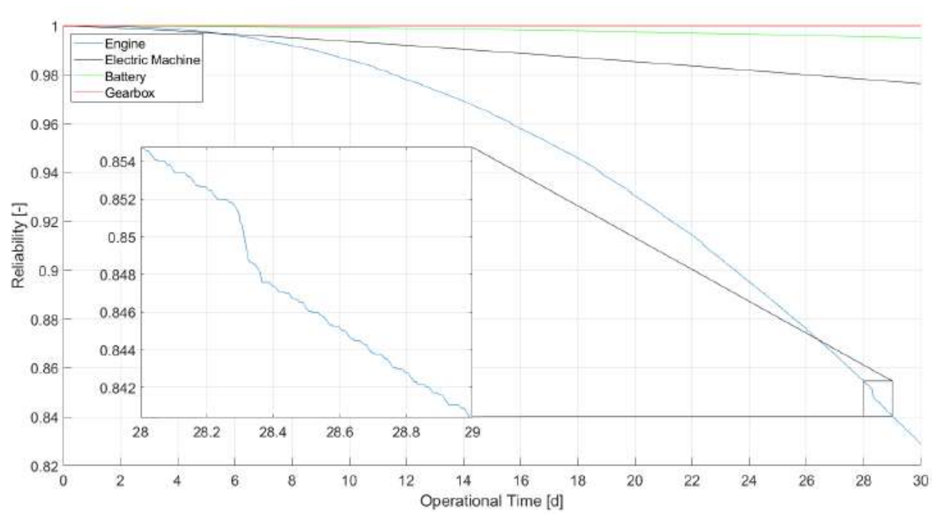

Figure 6. *Derived components' reliability time variations*

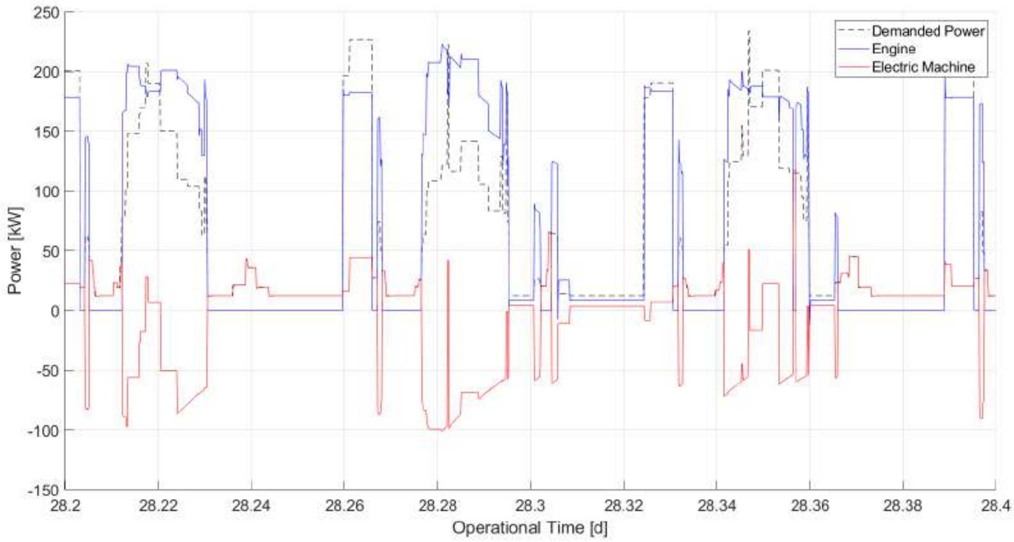

Figure 7. *Power output and power demand*

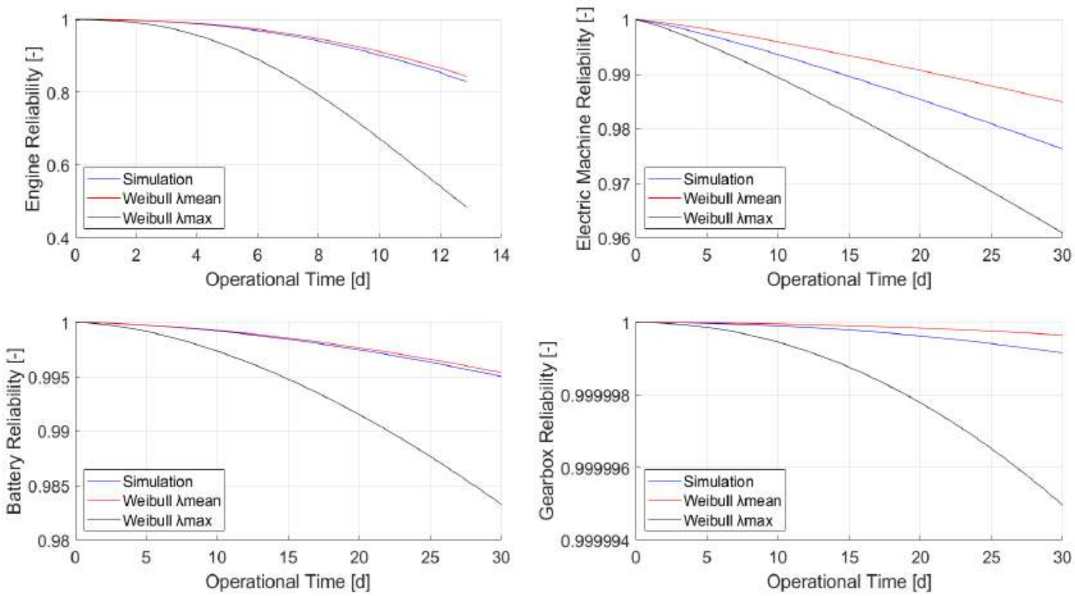

Figure 8. *Comparison of the components' reliability with theoretical distributions*

Finally, to demonstrate the temporal behavior of the system's reliability calculated from the developed DBN, different time slices of the dynamic Bayesian network (showing the reliability and unreliability of its components) at days 15 and 30 are presented in Figure 9. From this figure, it is inferred that the engine's unreliability exhibits the highest values (increases faster compared to other components), whereas electric components of the power plant exhibit high reliability values, thus resulting in lower values of the system's unreliability.

It must be noted that the DBN can be used as a tool to estimate the system's reliability in future time slices, considering the current operating conditions, thus supporting the decision-making process.

8. Conclusion

In this study, a monitoring functionality for the operation of an autonomous ship power plant is proposed. The employed methodology considers operating conditions of the power plant to assess the health state of components and the system by developing and using a DBN.

Results demonstrated the usefulness of extended monitoring functionalities that include both conventional performance metrics and reliability. The latter was employed to estimate

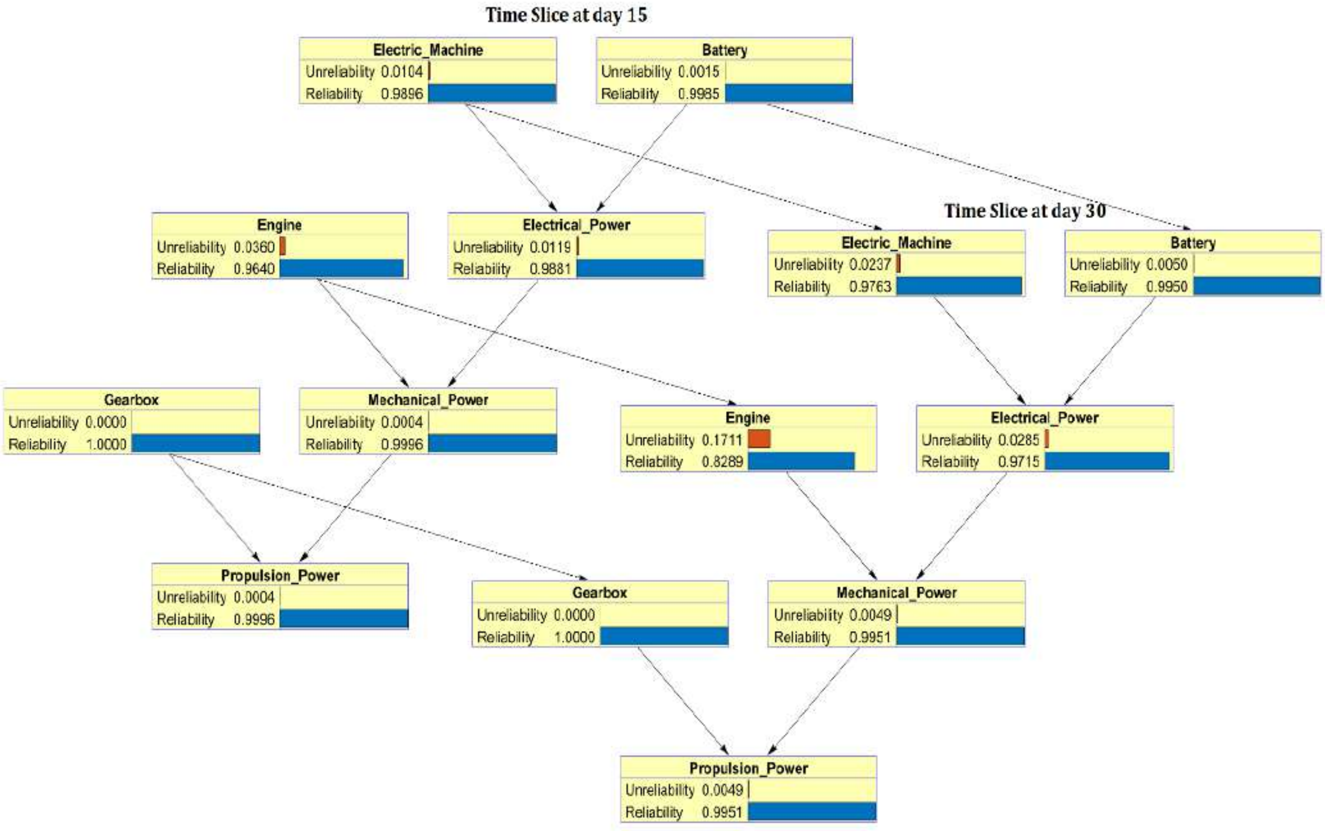

Figure 9. *Time slices of the dynamic Bayesian network*

the components' degradation. Future studies will include the use of this functionality as an enabling technology to develop the required automatic self-awareness of the power plant for facilitating the decision-making process in autonomous ships plants operations.

Authorship Contributions

Concept design: C. Tsoumpris, G. Theotokatos, Data Collection or Processing: C. Tsoumpris, Analysis or Interpretation C. Tsoumpris, Literature Review: C. Tsoumpris, Writing, Reviewing and Editing: C. Tsoumpris, G. Theotokatos.

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Data-driven Ship Domain for Open Water Navigation

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Abstract

Navigation is a significant part of shipping safety as it directs and delivers the physical mass of commercial assets. In addition to navigation, ship domain is a frequently used navigation safety concept in mariner's terminology. However, the perception of ship domain lacks the terse representation because of multidimensional factors of the sea environment. This study has proposed not only a data-driven ship domain that can be compared with theoretical counterparts to validate navigation safety understanding in open waters but also a unique minimum distance passage representation for ship domain. This study proposes ship domain visualization for ship-ship encounters only in the closest passages rather than all ship trajectories. Results show that ship domain boundaries are consistent with former studies, but such results provide in-depth inference.

Keywords: Ship domain, AIS, Visualization

1. Introduction

Navigation safety is a fundamental necessity in each technological update in the maritime industry. These technological transformations are inevitable, and they may contain a number of shifts in traditional shipping behavior. The shipping industry is a great ecosystem with its subsystems and stakeholders such as mariners, shipping companies, ports, shipyards, insurance firms, training centers, regulatory bodies, and unions. These contributors aim to achieve the safe transportation of goods because seaborne transportation is safer and more economical than other transportation types. Although maritime transportation is the best transportation type in international trade, the seaborne trade has many risks. According to the European Maritime Safety Agency [1], among ship accidents from 2014 to 2020, 12.8% are collisions and 17.2% are contacts. Furthermore, de Vos et al. [2] have presented that among ship accidents from 2000 to 2018 worldwide, 20% are collisions, 6% are contacts, and 43% are hull-machinery damages. In addition, they have presented that 44% of the accidents worldwide are navigation related and assumed that autonomous ships will reduce the number of navigation-related accidents in the future.

These maritime-related accidents have been analyzed by many researchers [3-5], and the community has proposed a number of indicators [6-12] that can reveal the degree of ship-to-ship collision. The main source of these studies is simulation logs and automatic identification system (AIS) data. Furthermore, activity data measures such as numbers of port calls, numbers of vessel days, and nautical miles sailed have been presented by some researchers [13]. Among these indicators, the ship domain is of utmost importance because it is the fundamental perception of sea environment for the officer on watch (OOW). The ship domain is a navigation safety structure abstraction model since its introduction by Fujii and Tanaka [14] as "a two-dimensional area surrounding a ship which a navigator must avoid-it may be considered as the area of evasion." After Fujii and Tanaka [14], the ship domain was described as "the effective area around a ship which a navigator would like to keep free with respect to other ships and stationary obstacles" by Goodwin [15]. The ship domain is a fundamental navigation safety indicator that most of

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the researchers used in their problem. Collision avoidance, collision risk assessment, and path planning studies have already used ship-domain-based approaches in navigation analysis.

However, no consensus has been found on how a ship domain should be. Despite the theoretical [16-18] and empirical ship domain proposals [19], the open sea environment perspective of the ship domain has not been emphasized with empirical data. The open sea is an unbiased environment because all congested waters have their own specific characteristics such as shallow waters, buoys, current, land obstacles, and local traffic. Thus, this study proposes a novel empirical ship domain exploration for open waters from AIS data. The novelty of the study is based on the utilization of AIS data with minimum passing distance data instead of all ship trajectories. In addition, this study aims to reveal ship domains in open waters with the minimum passing distance approach rather than all trajectories of ship traffic.

In this study, open waters refer to a navigation area that differs from congested waterways (port entrance and coastal waters) and narrow channels and provides more free navigable space to ships. Open waters may substitute for international waters, which start from the end of contiguous zones [24 nautical miles (NM)]. The main contribution is revealing the ship domain structure of each vessel type in open waters using a novel minimum passing distance approach. This has been achieved with only one ship-ship encounter that has the closest distance rather than all ship trajectories [19].

2. Literature Review

Ship domain is a recommended free space around a ship that no other ships/obstacles should enter. Determining the ship domain is achieved by statistical approaches based on radar [15] and AIS [19] and analytical approaches [20], [21]. However, determining the ship domain size and shape, which heavily emerge as circle and ellipse-like, is based on mariners' experience. Goodwin's [15] statistical circle ship domain, inferred from simulation results, proposes different distances for each direction (Figure 1a). However, Fujii and Tanaka's [14] elliptical model is 1.6 ship length (L) for breadth and 4 L for longitudinal (Figure 1b). This model has been extracted from a high volume of ship position records in Japanese waters. Coldwell [22] separated breadth as 1.75 L for port and 3.25 L for starboard side. However, the longitudinal distance is 6.1 L. Despite measurement differences among these former ship domains; the understanding represents the perception of mariners.

Furthermore, Kijima and Furukawa [23] have introduced a ship domain based on the blocking area concept (Figure 2a). The watching area is a threshold that mariner should decide avoidance maneuver in the case of any invader ship, whereas the blocking area is not permitted for other ships. The parameters (R_{bf}, S_b, R_{ba}) are determined by ship length, speed, breadth, tactical diameter, and advance, which are the main characteristics of a ship. A similar work has been proposed by Dinh and Im [24], who proposes the minimum distance of the blocking area as between 2.8 and 4.6 L based on the decision of 61 experts. Fuzzy ship domain approaches are also identified. For example, Pietrzykowski [16] has proposed a fuzzy polygon-shaped ship domain for restricted waters at different safety levels. Another study with the same model has been proposed for open waters [25] (Figure 2b). Distances are not normalized, and γ refers to fuzzy memberships of the navigational environment. On the contrary, an empirically calibrated ship domain for

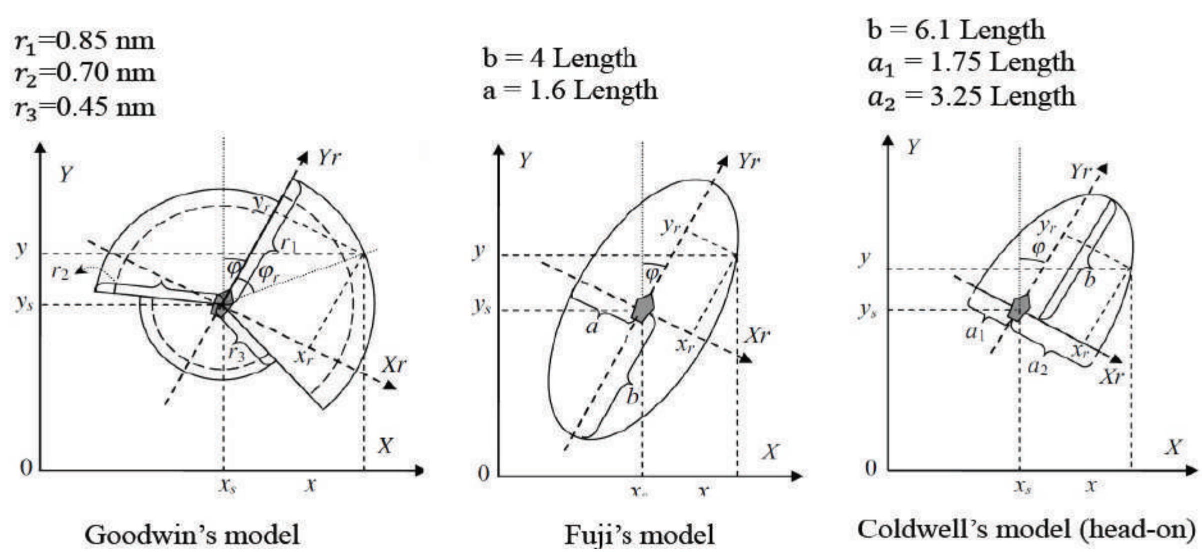


Figure 1. *Ship domains*

confined waters is provided by Wang and Chin [26], which can change with speed parameters (Figure 2c). Authors have compared this model with other models [14,16] with different scenarios and concluded that the proposed ship domain is potentially more adaptable in revealing ship separation.

Liu et al. [27] have extended Fujii and Tanaka's [14] model with a dynamic model for restricted waters by considering the ship behavior and waterway structure to apply capacity analysis. Furthermore, Rawson et al. [28] present a ship domain model based on AIS data for river basins with 22 h of data. Unlike the abovementioned studies, Du et al. [29] provide available maneuvering margin, which indicates a proximity measure to reflect the dynamic nature of encounters in Baltic Sea. On the contrary, Hansen et al. [19] have provided an empirical ship domain based on AIS data in busy waters by integrating ship positions below 3500 m. They have revealed a comfort ellipse (Figure 3) that has a length of 8 L and a breadth of 3.2 L, which is consistent with Fujii and Tanaka's [14]. As they focus on restricted and busy waters, they recommend studying other areas such as open waters in the future. In Hansen et al.'s [19] study, intensity analysis includes all ships around rather than the closest pair. Intensity analysis has been conducted with all other ships' geospatial positions, which may cause a biased representation of the ship domain perception. The AIS was data obtained from three particular areas such as Fehmarnbelt Channel (~9 NM wide), Great Belt Bridge (~9 NM wide), and Drogden Channel (~7 NM wide), which may not be assumed as open sea.

Furthermore, Szlapczynski and Szlapczynska [17] have reviewed the ship domain studies in detail, which can be referred to any further query about the ship domain. They have concluded that the latest ship domain research is similar to some of the classic ones. The length and dimensions are similar in each ship domain study because they are relatively a complex problem to predict ship domain. Consequently, each ship domain approach has provided sizes and shapes of free spaces from its own ship (OS) to enhance the navigation safety. However, this novel study differs from former studies because it proposes a data-driven ship domain for open waters rather than restricted/busy waters [19] and takes only the closest ship pairs into consideration rather than all ship trajectories in the sea, thereby revealing the OOW perspective rather than the maritime traffic structure.

3. Methodology

The methodology used in this study has been presented in Figure 4. Raw AIS data contain an insurmountable volume of data segments, which should be explored and cleaned

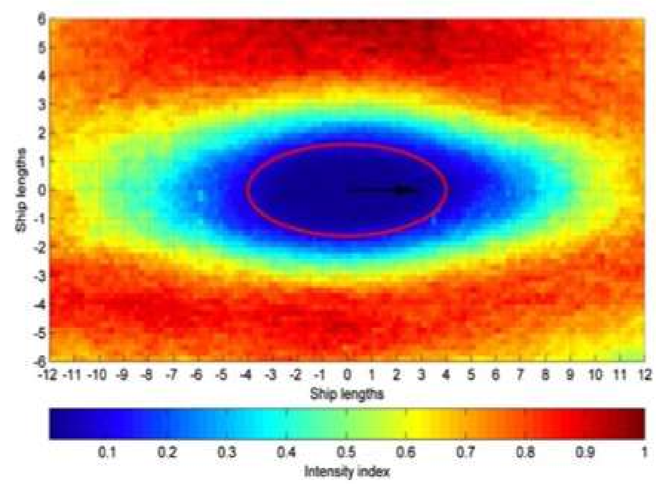
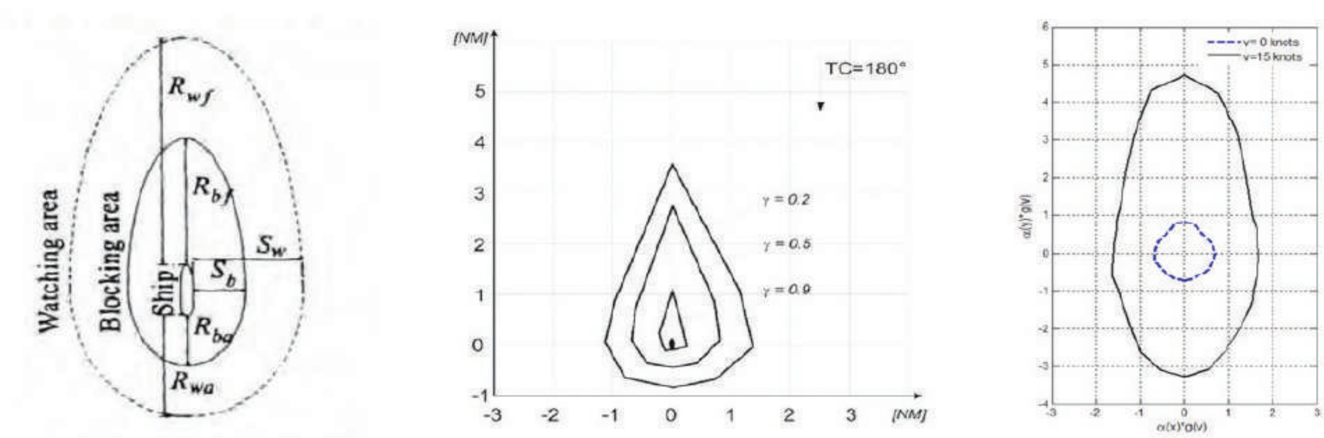


Figure 3. *Hansen et al. [19] ship domain model*



(a) (b) (c)

Figure 2. *Further ship domains*

before further analysis. Therefore, raw data have been clustered, and new features such as the relative position of other ship, number of ships in 5 NM, number of ships in 10 NM, day/night, and minimum passing distance have been obtained. The filtering and data cleaning steps along with features will be extensively explained in the next subsection. This methodology, containing relative positions and distances, provides a visual ship domain structure for open waters, which pave the way for detailed correlation analysis of parameters with ship domain.

After obtaining data, visualization has been achieved with relative bearing and distances. Correlation analysis, ship domain parameters, and density visualization outputs provide foundations for detailed analysis of ship domain perception in an open sea environment.

3.1. Data Analysis

The AIS data of the Mexican Gulf has been used in this study. The dataset contains 3 years (2015-2017) of AIS transmission from merchant vessels in open sea environments between contiguous zones (24 nautical miles) and the exclusive economic zone (200 nautical miles) obtained from marinecadastre website. All data analysis steps have been implemented in the Python environment. In addition, the raw dataset contains around 47 million observations, and after filtering by geographical aspect and cleaning, 1,814,863 unique observations have been obtained for detailed analysis. For example, only the observations that are outside the contiguous zone (24 NM) have been taken into consideration. Relative position of other ship, number of ships in 5 NM, number of ships in 10 NM, day/night, and minimum passing distance have been obtained after feature engineering of the raw dataset. All these features are obtained after the encounter situation with minimum distance has been detected. Only the minimum distance of all distance measurements is considered. A brief algorithm of how to obtain minimum passing distance has been shown in Figure 5.

The number of ships are the other ship numbers in the respective range at the time of minimum passing distance. Furthermore, minimum passing distance is the distance of another ship from its OS when the time to the closest point of approach (TCPA) is zero. The visual representation of the minimum passing distance has been shown in Figure 6.

The minimum passing distance (y) is the distance when TCPA is zero, which indicates the moment of the closest distance between two encountered ship pairs. The previous trajectories have not been considered to distinguish the closest encounter. Otherwise, the number of trajectories out of the real ship domain may be excessive than expected, which in turn may affect density analysis. In fact, this moment is of utmost importance for mariners because the

Algorithm 1 Minimum passing distance pseudocode

```
function MP-CPA(shipID, shipCorr, time)
    D ← Group all shipCorr by ShipID                         ▷ First grouping
    D ← Eliminate groups below 20 ▷ Eliminate low sampled observations.
    D ← interpolate by D[time]
    S ← Divide by two hours period
    For each divided S execute:
    for each ShipCorr in S do
        for each ShipCorr in S do
            S[Distance] ← Distance between ships          ▷ Get all distances
            S[MinimumPD] ← minimum S[Distance]             ▷ Get minimum
distance
        return S
```

Figure 5. *Pseudocode of minimum passing distance calculation*

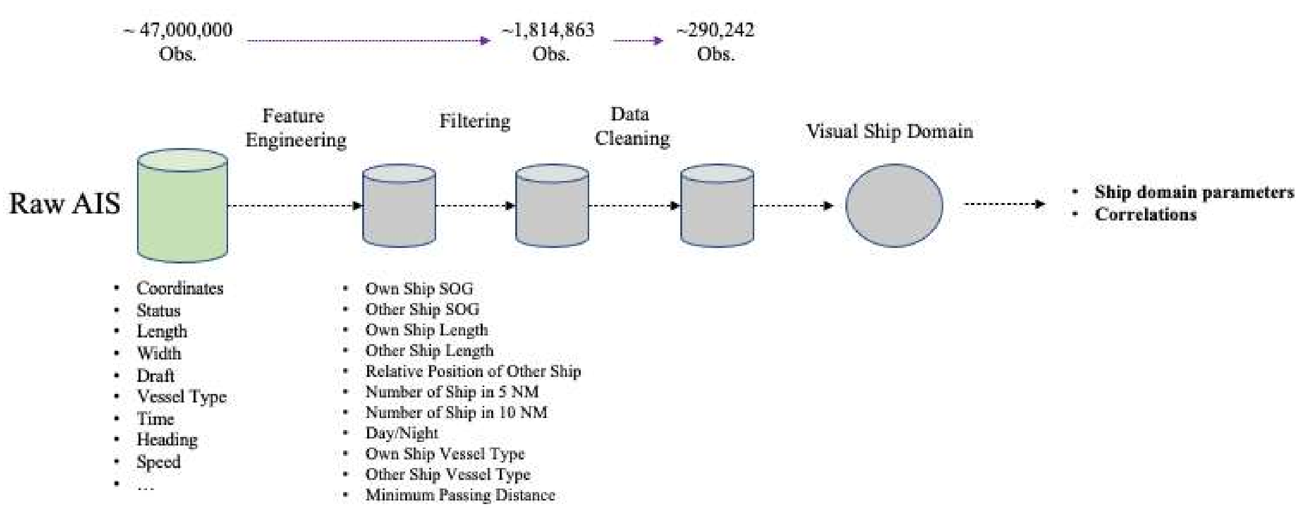


Figure 4. *General methodology of the study*

AIS: Automatic identification system, SOG: Speed over ground relative bearing and distance are important when TCPA is zero. Furthermore, it may represent the perception of mariners in any encounter situation. This unique way of representing maritime structure paves the way for in-depth understanding of mariner perception in navigation. This approach may reveal mariner's perception more than other density or statistics-based ship domain approaches because mariners deliberately prefer only the minimum passing distance out of all trajectories in most cases.

The dataset represents the ship-to-ship pair's encounter in open sea every 2 h. After geographical filtering, ships that are underway and observations below 10 NM minimum passing distances (290,242 observations) have been considered. The correlation plot of the dataset in this phase has been presented below in Figure 7.

The number of ships in 5 NM has the highest correlation with the minimum passing distance, which is the visual representation of the data-driven ship domain approach. This result indicates that OOW takes closer ships into consideration instead of far ships. However, other features such as suboesophageal ganglion, width, length of OS, and target ship (TS) have nearly no correlation with minimum passing distance with ship-to-ship pairs that are in the 10 NM range. Another crucial point must be considered, namely, the normalization of the distance with regard to ship length. Correlation analysis provides different results when the distance is interpreted with regard to ship length (DistanceSL). Therefore, the number of ships in 5 NM has more correlation with DistanceSL than the number of ships in 10 NM. However, the same case is not valid for OS length and width because ship static features such as length and width have important perception in the eye of OOW. The descriptive statistics of these variables have been provided in Table 1.

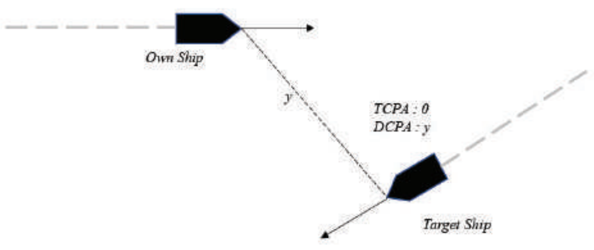


Figure 6. *Minimum passing distance representation*

TCPA: Time to the closest point of approach, DCPA: Distance at closest point of approach

Table 1. *Descriptive statistics of dataset*

Features	Mean	Std.	Min.	Max.
OS length	172.5	73.6	33	430
OS width	28.1	10.3	7	90
OS SOG	13.6	3.8	2	49.8
Number of 5 NM	0.96	0.69	0	8
Number of 10 NM	1.63	1.05	1	17
TS length	173.1	74.8	21	430
TS width	28	10.5	5	90
TS SOG	13.9	3.9	2	48.3
Minimum distance	3	2.53	0.05	10
Distance SL	48	65	0.5	588

Std.: Standard, Min.: Minimum, Max.: Maximum, OS: Own ship, SOG: Speed over ground, TS: Target ship

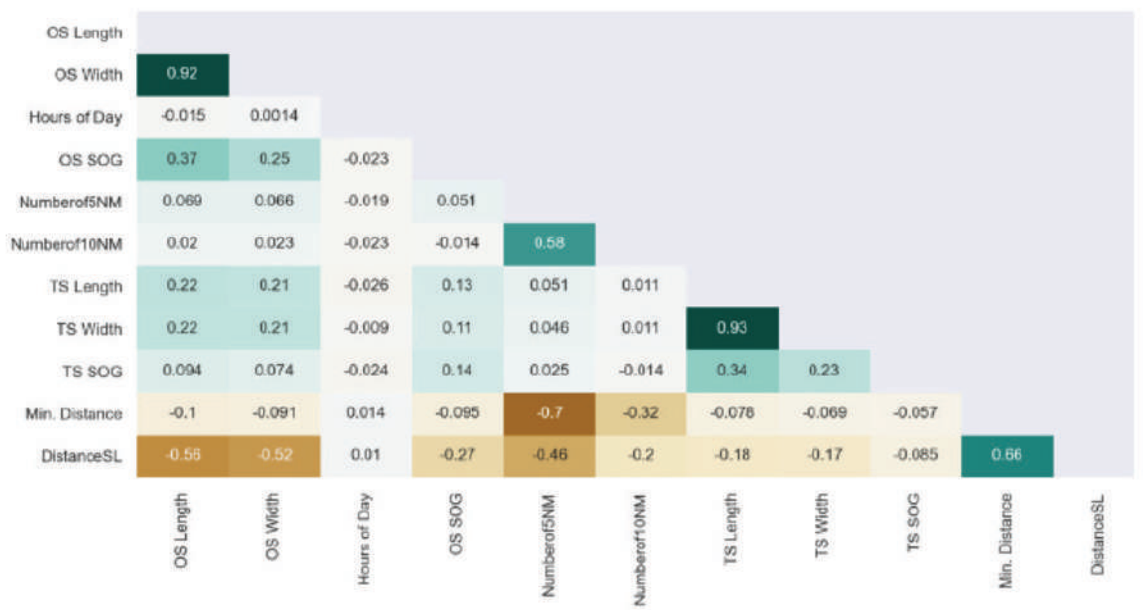


Figure 7. *Correlation plot of observations*

OS: Own ship, TS: Target ship, SOG: Speed over ground

The mariner perception is heavily determined by the static characteristic of the ship; thus, it is more plausible to construct an empirical ship domain approach on Distance SL rather than minimum distance [19]. The visual representation of the data-driven ship domain has been presented in the next section.

3.2. Data-driven Ship Domain

As discussed in the previous section, perceiving the distance among ship pairs with regard to ship length is important. Thus, the ship domain structure can be analyzed by visual distances with normalized distances, which in turn allows analysis of different sizes of ships. After detailed examination and processing of raw AIS data, the density of relative positions of TS based on OS with regard to OS length has been shown in Figure 8.

The density plot covers the area of 60 ship lengths, and density bins are divided into 100×100 pixels. The color of each pixel represents the number of ships in that spatial location. Although it is hard to figure out density below ~0.2, the central area is distinguishable, which can be deemed as the ship domain. The ship domain obtained from the perspective of the minimum passing distance is a circle-like domain rather than an ellipse. However, the port and aft sides seemed more comfortable for mariners in open waters because the density is high in these areas. In addition, the suitable distances are approximately 3.12 and 3.35 ship lengths from port and aft based on the density index boundary of ~0.3. Other distances are 5.28 ship lengths from the bow and 5.7 ship lengths from the starboard side. The kernel density estimation plot can show the boundaries in a more compact way. Considering that the density index and level curves have been normalized, the kernel density level curve of 0.3 corresponds to 0.08% of the observation. Based on the kernel density curves, a circle-like shape fits to the data more than an ellipse. Furthermore, the starboard-bow sector has been kept clear by most of the mariners. The reason why port and aft sectors are denser than other sectors may be the reasonable safety awareness that most of the mariners do not prefer to encounter other ships in the bow direction when TCPA is zero. This study proposes ship domain visualization based on the minimum safety distance; thus, this kind of inference could be captured (Figure 9).

Furthermore, the reason why the starboard sector is larger than the port sector as stated by [22] can be revealed in a more concise way using the proposed method. A more detailed data-driven ship domain by vessel types has been provided in Figure 10.

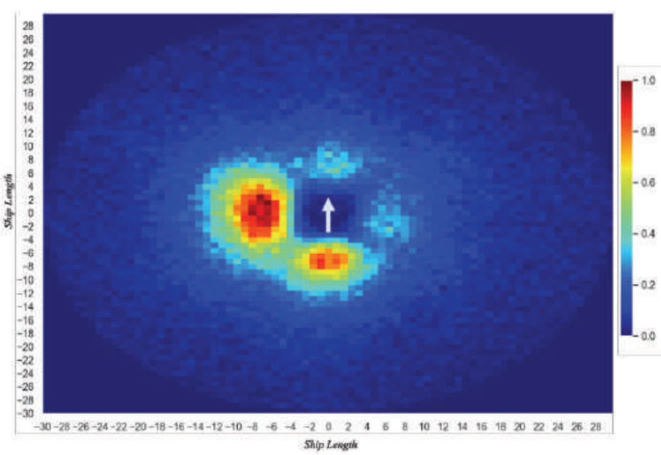


Figure 8. *Density plot for open waters*

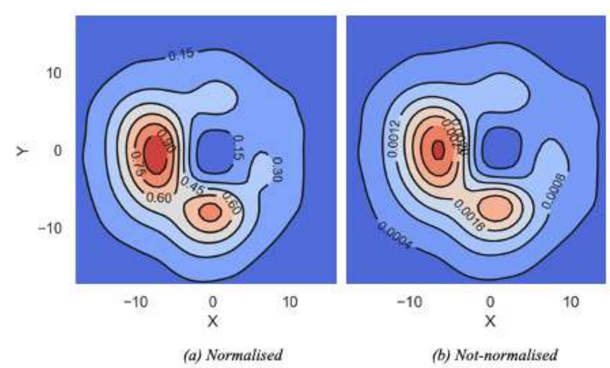


Figure 9. *Kernel density estimation of the minimum passing distance*

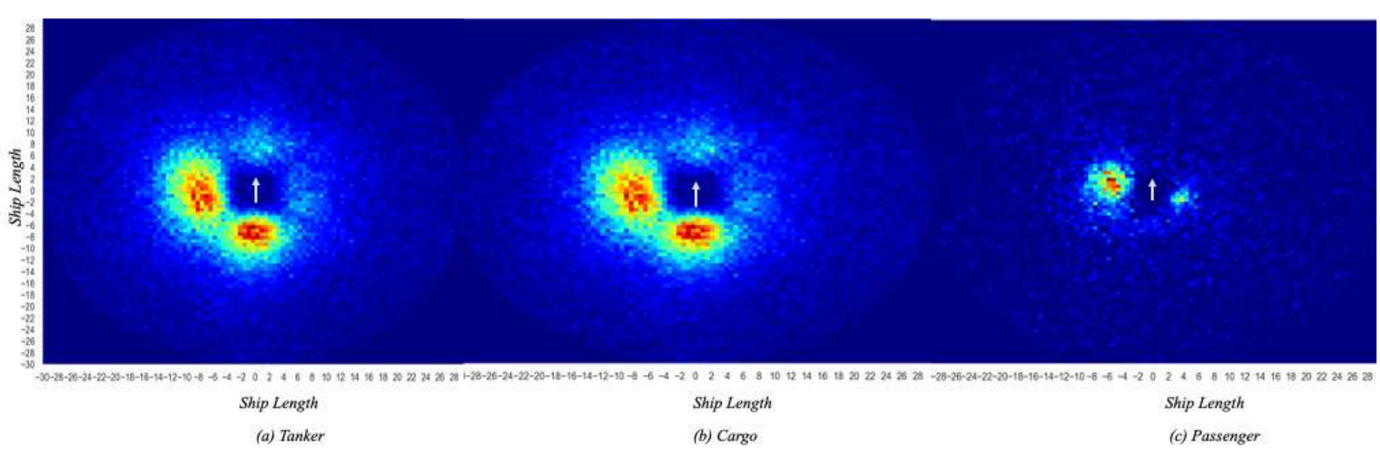


Figure 10. *Density plots for open waters by vessel types*

Figure 10 presents another aspect of density plot by vessel type. Although tankers and cargo ships have similar visual density plots, they are quite different from passenger ships. The approximate circular distances have been presented in Table 2 for a closer look into ship domain boundaries. The boundaries of passenger ships are a slightly below than other ship types. In addition, the distance in the bow sector is the highest among all sectors for all ship types. In particular, tankers have the highest distance in the bow sector. Furthermore, the port sector is more comfortable than starboard for all mariners except for passenger ships.

Former ship domain dimensions [14,22] are quite similar to the obtained results. For example, Fujii and Tanaka's [14] model proposes four ship lengths in the bow and aft direction for the ship domain, whereas the present study has obtained 3.35 and 5.28 ship lengths for the aft and bow, respectively. However, lateral radiuses are quite different. On the contrary, Coldwell's [22] model proposes 1.75 and 3.25 ship lengths for the port and starboard, respectively. The obtained results (3.12 and 4.5 ship lengths) are consistent with these measurements. Furthermore, these results support the view [19,22] that mariners would prefer larger spacing in the starboard sector in ship-to-ship encounter situations.

Table 2. *Approximate ship domain boundaries by vessel types*

Vessel type	Port (~ SL)	Starboard (~ SL)	Aft (~ SL)	Bow (~ SL)
Tanker	4.1	4.5	3.5	5.5
Cargo	3.5	4.6	3.6	4.6
Passenger	2.5	2.0	3.5	3.8
All ships	3.12	4.5	3.35	5.28

4. Result and Discussion

This study presents a distinguished data-driven ship domain density plot using the minimum passing distance approach. The boundaries of the ship domain presented in this study differ from other statistical and empirical ship domains in some studies. Although former empirical ship domain studies analyze ship coordinates as a whole without any further preprocessing with feature engineering, the minimum passing distance approach provides some additional clues about mariners' perception. For example, mariners not only prefer additional distance in the starboard and bow sector, but also keep their starboard and bow sector clear when TCPA is zero. Furthermore, the practical ship domain of tankers is more than that of cargo and passenger ships. The safety boundary limit of OOW on tankers seems to be higher than OOW on other ships. Thus, the safety precautions and preparedness are stricter in tanker ships.

Hansen et al.'s [19] comfort ellipse (Figure 3), which has a length of 8 L and a breadth of 3.2 L, is larger than this proposed ship domain. However, the aft and bow radius should be different. Furthermore, the open water ship domain should be larger than the busy channel. Therefore, all ship trajectories may result in biased ship domain representation.

Another critical point of the analysis is the negative correlation between ship length and the minimum passing distance. For example, correlation between OS Length and DistanceSL is -0.56, which indicates that as the ship size becomes larger, the distance between ships becomes smaller. Thus, the opposite could be expected. However, the reason for this negative correlation is that as the ship size increases, the possibility of following traffic lanes in open sea increases, which result in close passing distance. The basic understanding of a ship domain is to reveal the minimum area (blocking area etc.) that other ships enter. As other ships get closer, a general pattern may be observed, that is, they do not enter into ships area anymore. A more detailed look into this issue can be seen in Figure 11.

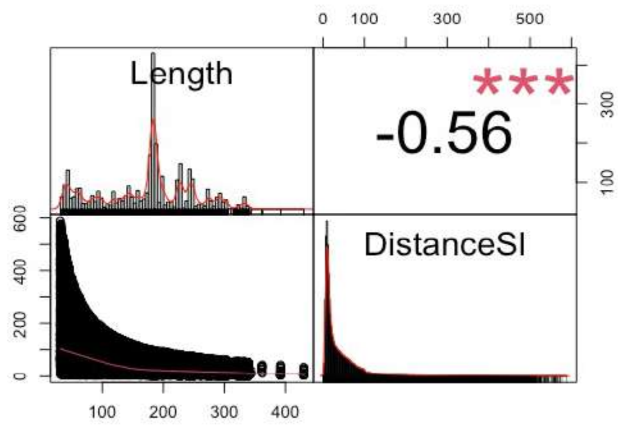


Figure 11*. Scatter plot of OS Length and DistanceSL*

OS: Own ship

The minimum DistanceSL is 0.55 among observations above 300 m ship length, whereas it is 3.48 among observations above 400 m ship length. The critical point for this threshold is 335 m ship length. Notably, more than 1000 observations can be made above this threshold. This finding indicates that the minimum passing distance does not decrease after some point, which is consistent with the ship domain concept. The fitted curve with a red line shows this understanding well. The mean value of the fitted curve after 335 ship length is 12 ship length. Finally, this study proposes that the main determinants of ship domain boundaries are ship length and the number of ships around as their correlations are the highest with a minimum passing distance.

5. Conclusion

This study presents a novel approach to determine ship domain boundaries by using the minimum passing distance approach. The AIS data obtained from Mexican Gulf have been filtered, cleaned, and examined before feature engineering steps, and the unique dataset has been obtained for further analysis. Visualization of minimum passing distance spatial point density provides a data-driven ship domain that indicates the concise perception of OOW rather than the basic density plot of maritime traffic around a ship. The result of the study provides a similar but more in-depth understanding of ship domain boundaries. This study focuses on open waters; thus, other regions such as narrow channels and busy waters can be analyzed using this approach in future studies. Furthermore, as the number of ships around is highly correlated with the minimum passing distance, this parameter can be designed using different thresholds other than 5 and 10 nautical miles in further research.

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A Set of Criteria for Logistics Center Development: A Fuzzy Analytic Hierarchy Process

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Abstract

This research aimed to determine and prioritize a set of criteria for the development of logistics centers. Both qualitative and quantitative data collection methods were used to achieve the research aim. Content analysis and semistructured interview techniques were used as the qualitative research methods. Semistructured interviews were conducted with 14 experts, including seven logistics center managers and seven logistics company managers who have worked in a logistics center. The qualitative research revealed eight main criteria and their subcriteria, including location, infrastructure, activities and services, ownership and management, market conditions, regulations, benefits, and horizontal collaborations. The fuzzy analytic hierarchy process was conducted with 18 professionals/experts from different groups of logistics center stakeholders to prioritize the set of criteria. The results were interpreted based on the findings. Among the eight selected criteria, "location" (22%) was the most important criterion, followed by "market conditions" (20%).

Keywords: Logistics center concept, Logistics center development, Criteria set, Fuzzy analytic hierarchy process

1. Introduction

Logistics centers act as a node in the supply chain, connecting suppliers and customers; therefore, the logistics center concept has evolved in tandem with supply chain management, third-party logistics, intermodality, and sustainable transport concepts. As the supply chain becomes more complex, continual development of value-added, time-based logistics services is required to meet customer demands. The main facilitators of intermodal transport are logistics centers, which bring together the logistics operators offering various transport modes and services to provide synergic solutions. Environmental concerns also play an important role in the development of logistics centers. An important goal of logistics center development is switching to more environmentally friendly transport modes, such as railways and inland waterways rather than roads.

Logistics centers first appeared in the United States of America about 40 years ago, and as the demand for efficient sustainable logistics systems increased, they spread all over the world [1]. Successfully developed logistics centers improve transport infrastructures and logistics market conditions, reduce costs, and increase logistics system quality. In addition, public authorities and private actors can collaborate more effectively to attract and facilitate international trade and investments in a particular region [2]. Logistics centers also help to improve the environmental performance of logistics systems in a region by reducing the number of lorries on the roads, which decreases traffic congestion, accidents, road maintenance costs, and pollution [3]. They are also important nodes that can increase the value-added services in the logistics value chain, thereby increasing supply chain competitiveness. Logistics centers can have different roles, including specializing in the demands of certain products and markets in a global logistics

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network [4]. European Union (EU) transport policies have resulted in the formation of many logistics centers to enhance intermodality and interoperability, alleviate urban traffic congestion, increase transport efficiency, encourage innovation, and decrease transportation costs [5].

Logistics is a relatively new industry in Turkey that has progressed in recent years. Turkey is becoming a bridge between East and West in terms of international trade and logistics. Many authorities claim that Turkey will be a regional logistics base. Many international companies have already been drawn to its logistics sector because of its rapid growth [6]. Since the early 2000s, both the public and private sectors in Turkey have established logistics centers. Since then, nine public logistics centers have been completed out of 21 projects, and three private logistics centers have begun operations [7].

Despite the common use of the term "logistics center" in Turkey and other parts of the world, the term itself, concept definition, and features differ in the literature and in practice because logistics centers continue to evolve and expand. Thus, few keywords were selected to conduct a literature search for related papers. The keywords "logistics centre," "logistics center," "dry port," "freight village," and "inland port" were searched in Web of Science and Google Scholar from 1970 to 2018. The studies found mainly focused on the logistics center concept, location selection, transport chains, dry port evaluation and development, intermodality, handling operations, and value-added services. However, no research has been conducted to suggest a set of criteria that includes all aspects of logistics center development. Therefore, the main focus of this research was on determining and ranking a set of criteria for logistics center development.

This paper first analyzes the concept of logistics centers in the literature to identify some criteria for logistics center development. Second, section 3 describes the research methodology, and section 4 presents the findings of semistructured interviews with managers of logistics centers and managers of logistics companies located in logistics centers in order to provide an improved understanding of the current situation and expectations in Turkey. Thereafter, the fuzzy analytic hierarchy process (AHP) is used to prioritize the criteria set and compare the perspectives of different stakeholders. Section 5 discusses the results, and finally, section 6 states our conclusions and recommended topics for future research.

2. Literature on Logistics Center Concept

Although logistics centers first appeared nearly 40 years ago in the United States before they spread to EU countries, the term "logistics center" is often confusing. Rimienė and Grundey [1] evaluated the number and scope of logistics center definitions and concluded that a logistics center can be a freight village, transport node, or distribution center. Notteboom and Rodrigue [8] labeled the inland facilities in the hinterland networks of ports as "inland nodes." These nodes have been referred to as dry ports, inland terminals, inland ports, inland hubs, inland logistics centers, and inland freight villages. According to Roso [3], the basic idea behind the concept of dry ports is that they are directly connected to ports by rail in order to increase the capacity and productivity of the ports. As international trade grows, transportation facilities also grow, particularly container traffic and port facilities. The increase in container shipping highlights the importance of logistics centers in ports and encourages their use [9]. Logistics centers with direct rail connections to ports are called dry ports. These dry ports are vital for efficient intermodal transport and efficient access from and to seaports [10,11].

Logistics centers are a unique type of transport node. A logistics center can be referred to as a freight village, logistics node, or distribution center [1]. Some authors refer to a logistics center as a broad concept that encompasses all companies that engage in transportation and logistics activities [12]. Other authors refer it to as a functional equivalent of freight villages [13]. Studies have shown that both the terms and concepts vary. The logistics center concept is frequently combined with facilities, such as container yards, distribution centers, distriparks, dry ports, freight villages, inland container depots, inland terminals, intermodal terminals, freight terminals, transport nodes, and warehouses [1].

When we analyze the definitions of inland logistics facilities associated with the logistics center concept, we realized that these facilities can provide every aspect, from simple logistics services to advanced logistics services. In terms of regional aspects, these facilities range from local to regional to national to international; some of these centers provide international shipping services, while others provide urban logistics operations (local distribution). Many warehouses or terminals are also called logistics centers by their owners [14]. These facilities also range in geographical coverage, volume, capacity, and services [1,13]. Although there are several useful definitions of logistics centers, establishing a general definition is difficult. Therefore, different definitions that emphasize the functional characteristics are commonly used rather than a universal definition [12].

Table 1 summarizes key points in the literature that are used for differentiating between different types of facilities and identifying the functional characteristics of the terms associated with the logistics center concept.

The terms "logistics center" and "logistics village" are mainly used in Turkey, and the facilities mainly share the same characteristics as other facilities in the world. We prefer to use the term "logistic center" in this paper because of the features of existing formations in Turkey and its common use.

Unlike the definition, the objectives and purposes of logistic centers appear to have a consensus. The objectives of logistics centers according to different authors are summarized as follows:

• To enhance intermodal transport, regional economic activities, land use, and local commodity distribution [15];

• To serve a variety of purposes, such as cargo transshipment, production synchronization, and business and trade facilitation [16];

• To strengthen the logistics capability of a country and transform it into a more attractive competitive market [16];

• To support the creation of seamlessly integrated transport networks [2];

• To enhance the market attractiveness and competitiveness of logistics companies [2];

• To achieve a sustainable competitive advantage for transport and logistics companies [17];

• To create synergies and collaboration between transport and logistics companies [18]; and

• To improve the economic and productive performance of transport and logistics companies [18].

Table 1. *Comparison of the characteristics of the terms associated with the logistics center concept [1,13]*

Size	Term	Key Points and Activities
XS	**Warehouse**	• Storage of goods • Usually belongs to only a single company
S	**Distribution Centre**	• Warehousing • Shipping and receiving • Cross-docking • Production flow rather than storage • Large warehouses or clusters of warehouses
	Container Yard	• Temporary storage of containers • Cleaning and repairing of containers
M	**Inland Container Depot**	• Located in the hinterland of a gateway port • Container handling and temporary storage • Container flow rather than storage • Basic customs clearance • Inspections
	Intermodal Terminal	• Transshipment of goods between rail, road, and other transport modes • Consolidation of intermodal freight
L	**Inland Port/Dry Port**	• Located in the hinterland of a gateway port and directly connected to a seaport by rail • Provides all the services that seaports provide except ship loading/unloading • Aims to mitigate the congestion at main port terminals • Handles all types of cargo • Offers full customs-related services
	Logistics Center	• All logistics activities are carried out by various operators • Handles all types of cargo • Includes warehouses, distribution centers, storage areas, offices, and truck services
XL	**Freight Village**	• Synonymous with logistics centers but differs in scale • Offers a broader range of services than logistics centers, such as banks, restaurants, repair services, cleaning services, and education facilities • A centralized management and ownership structure
XXL	**Mainport Terminal**	• Generates numerous activities both inside the facility and within its periphery • Handles large volumes of freight • Includes major seaports and airports with worldwide connections • High trade and passenger flows

3. Methodology

In this research, content analysis of the literature and semistructured interview techniques were used as qualitative research methods, while the fuzzy AHP method was used as a quantitative research method. The semistructured interview method was used to provide a better understanding of the current situation and expectations in Turkey. It mainly consisted of face-to-face and open-ended interviews with logistic companies located in logistics centers and the management of logistics centers. Simultaneously, field observations were conducted by visiting logistics centers. The primary purpose of the literature review, interviews, and field observations was to provide an improved understanding of the research field and to collect the data required for the fuzzy AHP method. Subsequently, the fuzzy AHP technique was used as a quantitative method to analyze the data collected using the qualitative method. Figure 1 shows the scheduled process.

3.1. Content Analysis of the Literature and Interviews

To conduct a literature review, the keywords "logistics centre," "logistics center," "dry port," "freight village," "inland port," and "logistics village" were searched in the Web of Science and Google Scholar from 1970 to 2018. The most cited articles were selected for content analysis. The majority of the articles found in the literature using the keywords "logistics centre" and "logistics center" focused on the concept of the logistics center and location selection. Location selection was also one of the most investigated topics in the articles found based on the keyword "dry port," followed by transport chains, dry port evaluation, and dry port development. The articles that were discovered based on the keyword "freight village" also mainly focused on intermodality, while articles found with the keyword "inland port" focused on handling operations and value-added services. Furthermore, studies on logistics centers in Turkey also mainly focused on location selection.

Content analysis was employed to analyze the data collected from the literature. It was carried out within the framework of the selected articles. The most commonly used features in the literature related to the development of logistics centers, dry ports, freight villages, inland ports, and logistics villages were defined as criteria, while statements explaining them were defined as subcriteria. The overall findings from the content analysis of the literature were conducted as a preliminary step before the semistructured interviews and fuzzy AHP were conducted. Areas to be interviewed were selected based on the findings from the content analysis of the literature.

Interviews were conducted with both private sector and state logistics centers. Among the private sector logistic centers, we selected the first one to start operating because all the others were either too small, in the project phase, or under construction. Among the Turkish State Railways (TCDD) logistics centers, four were selected because they

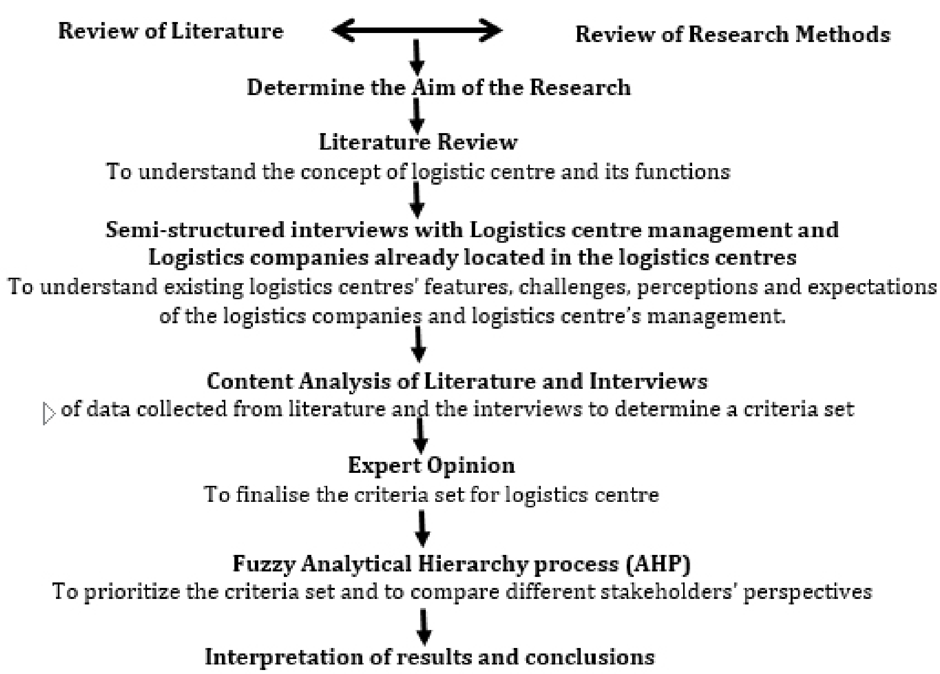

Figure 1. *Research process*

AHP: Analytic hierarchy process

are the longest-running TCDD logistics centers. In total, five logistics centers were selected, as shown in Table 2.

The Ankara Logistics Center is a private sector logistics center. It is also Turkey's first logistic center, which started operations in early 2011. Logistics companies in Ankara collaborated and formed Ankara Group Carriers Logistics Investments and Akaryakıt Tic. Inc. to launch the Ankara Logistics Center in 2004. The facility has an area of 700,000 m^2, with a closed area of 198,000 m^2. In the center, There are 5 blocks of rentable warehouses and bounded warehouses with a total area of 60 thousand m^2. The facility is designed to serve 400 enterprises, with a total workforce of 4,000 people. During the visit to the Ankara Logistics Center in June 2017, multinational logistics company managers and logistics center managers (presidents, vice presidents, and directors) were interviewed, and a site tour was conducted. A face-to-face semistructured interview method was used. The semistructured interview technique is more flexible than the structured interview technique. In the semistructured interview technique, the researchers prepare the interview protocol in advance, which contains questions that they intend to ask. Conversely, the researchers can influence the flow of the interview with different side questions or subquestions, allowing the interviewees to open and elaborate their responses, depending on the flow of the interview. The researchers may not ask these questions if the person has already answered them during the interview [19]. A specific set of questions was prepared for this purpose and asked each interviewee in the same style and order. The interview questions consisted of open-ended questions. The data were recorded using a recording device rather than by taking notes. All interviews were held from June 13, 2017, to June 15, 2017. On average, each interview lasted 45-60 min on the interview recorder. The recorded data were decrypted, and the answers were analyzed in the direction of the research aim.

State logistics centers are called "freight villages" in Turkey. TCDD planned to build 21 freight villages of different sizes in several locations in Turkey. Nine of these logistics centers began operations by the end of 2019, five are still under construction, and the rest are still in the study, project, or tender phase [20]. Out of nine logistics centers that are currently in operation, six TCDD logistics centers (Samsun Gelemen, Istanbul-Halkalı, İzmit-Köseköy, Uşak, Denizli-Kaklik, and Eskişehir-Hasanbey) were chosen for the interviews because they are the longest-running TCDD logistics centers; three of them have been in operation since 2010 and the others since 2014. The managers of the logistics centers were contacted by phone, and the interview questions were sent via email. One of the managers provided written answers by email, while the others were interviewed over the phone. After all, four of them were interviewed in total, and all interviews were held between June and August of 2017.

3.2. Fuzzy AHP Method

The fuzzy AHP method was used in this study to rank the criteria by importance. Scholars have criticized the traditional AHP because it does not consider the uncertainty associated with translating human judgment into numbers using natural language; the ranking of the AHP method is rather indefinite, and subjective judgments by perception, evaluation, improvement, and selection based on the preference of decision makers have a significant impact on the AHP results [21]. Although the pairwise formulation of the AHP consists of absolute numbers, the choices of decision makers are not always certain [21]. To overcome this problem, fuzzy logic is used in conjunction with the AHP to obtain detailed decisions of decision makers [21]. Chang's (1996) extent analysis method was used for the fuzzy AHP in this study. Many fuzzy AHP methods have been proposed by numerous authors, but Chang's approach is considered to be simpler than other fuzzy AHP approaches [22]. Chang (1996) proposed a new fuzzy AHP approach that uses triangular fuzzy numbers and the extended analysis method for comparisons. Triangular fuzzy numbers are a special variant of fuzzy numbers that are defined by three real numbers. They are expressed as (l, m, u). The parameters l, m, and u indicate the smallest possible value, the most likely value, and the greatest possible value, respectively. Figure 2 shows a representation of the triangular fuzzy number $\widetilde{M}$ [22]. Sun [23] developed a model integrating the fuzzy AHP and fuzzy Topsis methods, and he defined fundamental fuzzy AHP as follows:

Table 2. *Interview sampling groups*

Interview sampling groups	Number of Interviewees logistics center managers	Number of interviewees logistics company managers
Private sector logistics center (1)	3	7
State (TCDD) logistics centers (4)	4	-
Total	7	7
TCDD: Turkish state railways		

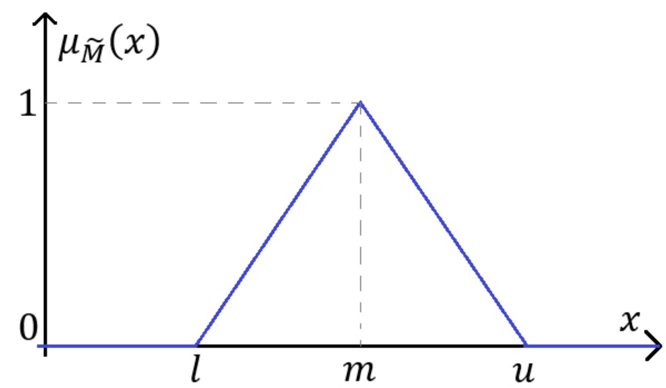

Figure 2. *Triangular fuzzy number* $\widetilde{M}$

The membership function $\mu_{\widetilde{M}}(x) : \mathbb{R} \rightarrow [0,1]$ of a fuzzy number $\widetilde{M}$ is defined by

$$\mu_{\widetilde{M}}(x) = \begin{cases} \frac{x-l}{m-l}, & l \le x \le m \\ \frac{u-x}{u-m}, & m \le x \le u. \\ 0, & otherwise \end{cases}$$

The operational laws of fuzzy numbers $\widetilde{M}_i = (l_i, m_i, u_i)$ and $\widetilde{M}_j = (l_j, m_j, u_j)$ are defined as follows [23]:

Addition of the fuzzy number $\oplus$:

$$\widetilde{M}_i \oplus \widetilde{M}_j = (l_i + l_j, m_i + m_j, u_i + u_j).$$

Multiplication of the fuzzy number $\otimes$:

$$\widetilde{M}_i \otimes \widetilde{M}_j = (l_i \,.\, l_j, m_i \,.\, m_j, u_i \,.\, u_j).$$

Subtraction of the fuzzy number $\ominus$:

$$\widetilde{M}_i \ominus \widetilde{M}_j = (l_i - l_j, m_i - m_j, u_i - u_j).$$

Division of the fuzzy number $\oslash$:

$$\widetilde{M}_i \oslash \widetilde{M}_j = \left(\frac{l_i}{l_j}, \frac{m_i}{m_j}, \frac{u_i}{u_j}\right).$$

Reciprocal of a fuzzy number:

$$\widetilde{M}_i^{-1} = \left(\frac{1}{u_i}, \frac{1}{m_i}, \frac{1}{l_i}\right).$$

The following sections briefly explain how the fuzzy AHP was conducted in this study.

Step 1. Definitions: Eight criteria and their subcriteria were determined by analyzing the qualitative research findings, and a questionnaire form was subsequently prepared for pairwise comparison matrices among all the criteria in the dimensions of the hierarchy system. The nine-level linguistic terms listed below (Table 3) was used for comparison.

Step 2. Contract pairwise comparison matrices: Comparison matrix linguistic terms were assigned to pairwise comparisons by determining which of the two dimensions was more important, as seen in the matrix $\widetilde{A}$ below [23].

$$\widetilde{A} = \begin{bmatrix} \widetilde{a}_{11} & \widetilde{a}_{12} & \cdots & \widetilde{a}_{1n} \\ \widetilde{a}_{21} & \widetilde{a}_{22} & \cdots & \widetilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{a}_{n1} & \widetilde{a}_{n2} & \cdots & \widetilde{a}_{nn} \end{bmatrix} = \begin{bmatrix} 1 & \widetilde{a}_{12} & \cdots & \widetilde{a}_{1n} \\ 1/\widetilde{a}_{12} & 1 & \cdots & \widetilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\widetilde{a}_{1n} & 1/\widetilde{a}_{12} & \cdots & 1 \end{bmatrix},$$

where

$$\widetilde{a}_{ij} = \begin{cases} \tilde{1}, \tilde{2}, \ldots, \tilde{8} \text{ or } \tilde{9} & , \ \textit{\textbf{i is relatively important to j}} \\ \tilde{1}, \tilde{2}^{-1}, \ldots, \tilde{8}^{-1} \text{ or } \tilde{9}^{-1} & , \ \textit{\textbf{j is relatively important to i}} \\ 1 & , \ \textit{\textbf{i = j}} \end{cases}$$

Table 3. *Membership function of the linguistic scale [23]*

Fuzzy number	Linguistic	Fuzzy number scale
~ 9	Perfect	(8,9,10)
~ 8	Absolute	(7,8,9)
~ 7	Very good	(6,7,8)
~ 6	Fairly good	(5,6,7)
~ 5	Good	(4,5,6)
~ 4	Preferable	(3,4,5)
~ 3	Not bad	(2,3,4)
~ 2	Weak advantage	(1,2,3)
~ 1	Equal	(1,1,1)

Step 3. Calculating geometric means: The geometric mean technique was used to define the fuzzy geometric mean and fuzzy weights of each criterion. The geometric mean technique for calculating weights $w\,i$ was extended to $\widetilde{\mathbf{A}}$. The geometric mean of each row was calculated using the fuzzy pairwise comparison matrix $\widetilde{\mathbf{A}} = [a_{ij}]$ [24]:

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \widetilde{a}_{ij}\right)^{1/n} = \left(\widetilde{a}_{i1} \otimes \widetilde{a}_{i2} \otimes \ldots \otimes \widetilde{a}_{in}\right)^{1/n},$$

and

$$\widetilde{w}_i = \tilde{r}_i \otimes \left(\tilde{r}_1 \oplus \tilde{r}_2 \oplus \ldots \oplus \tilde{r}_n\right)^{-1},$$

where $\tilde{a}_{in}$ is the fuzzy comparison value of the ith criterion to the nth criterion, $\tilde{r}_i$ is the geometric mean of the fuzzy comparison value of the ith criterion to each criterion, and $\tilde{w}_i$ is the fuzzy weight of the ith criterion, which can be indicated by a triangular fuzzy number, and $\tilde{w}_i = \left(l_{\tilde{w}_i}, m_{\tilde{w}_i}, u_{\tilde{w}_i}\right)$. Here, $l_{\tilde{w}_i}$, $m_{\tilde{w}_i}$, and $u_{\tilde{w}_i}$ represent the lower, middle, and upper values of the fuzzy weight of the i th criterion, respectively.

Step 4. Converting fuzzy numbers to non-fuzzy numbers: A fuzzy number is the outcome of the fuzzy synthetic decision reached by each criterion. Therefore, a nonfuzzy ranking method for fuzzy numbers must be used for the comparison of each criterion. In other words, defuzzification is the process of determining the best non-fuzzy performance (BNP) value. The mean of maximum, center of area (COA), and α-cut are common defuzzification methods for fuzzy number ranking. The COA method was used to determine the BNP value in this study because it is a simple and practical method that does not require the preferences of any evaluators. The BNP value of the fuzzy number r_i can be calculated using the following equation:

$$BNP_i = \frac{(u_{\tilde{w}_i} - l_{\tilde{w}_i}) + (m_{\tilde{w}_i} - l_{\tilde{w}_i})}{3} + l_{\tilde{w}_i}, i = 1, 2, \ldots, n$$

The ranking of the criteria can then be done based on the derived BNP value for each criterion.

The AHP survey was conducted from April to November of 2018. The survey was sent to 20 experts but 18 responses were received, which were divided into four groups, as shown in Table 4. The individual tables show comparisons of the main criteria and subcriteria, as well as the total results and individual results for each respondent group.

Table 4. *Fuzzy AHP survey sampling groups*

Fuzzy AHP survey sampling groups	Number of corporation surveys sent	Number of respondents
Logistics center managers	5	5
Logistics service providers	6	5
Logistics service buyers	5	4
Institutions	4	4
Total	20	18
AHP: Analytic hierarchy process		

4. Research Findings

4.1. Qualitative Research Findings

After the literature analysis and interviews, two different sets of criteria with subcriteria (one from the literature and one from the interviews) were obtained for logistics center development. To finalize the criteria set, the two different sets of criteria were gathered, and repetitions were removed from the list. The criteria and subcriteria sets were then presented to two expert academicians to obtain their opinions in order to assess sets credibility, applicability, and the extent to which they serve the research aim [25,26]. The appropriate arrangements were made in accordance with their recommendations. Finally, a set of criteria for logistic center development was determined, and the eight main criteria are explained below and displayed with their subcriteria in Table 5.

Criterion A. Location: This refers to the area where a logistics center is located. Logistics centers should be located in areas where services can be provided efficiently. The factors that influence the selection of the location of a logistics center are determined as subcriteria. For example, one of the logistics center managers clearly stated that "Logistics centers should be on the main roads without entering the city traffic. It should be equipped with railways, roads, and port connections, be environmentally friendly, and supply all kinds of logistics services." In addition, the other said, "When choosing the location of a logistics center, the region should be taken into consideration, such as the proximity to the organized industrial zones, the diversity of industrial activities, urbanization and planning decisions, and regional industrial development plans."

Criterion B. Infrastructure: This refers to the infrastructure that a logistics center should have. Essential infrastructure features for logistics centers are determined as the subcriteria. The interviewees stated that there must be organizations that regulate foreign trade, particularly customs. Ankara Logistics Center already has warehouses, bonded warehouses, banks, insurance companies, social facilities, restaurants, markets, car parks, vehicle repair facilities, filling stations, health and safety facilities, central fire detection, extinguishing systems, and 24-h security. All vehicles are recorded, and 112 emergency services are also available. One of the TCDD logistics center managers emphasized that it is necessary to have an advanced communication and information technology infrastructure.

Criterion C. Activities and Services: This refers to the activities and services provided by a logistics center. The activities and services that logistics centers have the most of, or should have, are defined as the subcriteria. The managers specifically emphasized that logistic centers improve the service standards of logistics companies by providing warehouse and bonded warehouse services and other value-added services that are available in the logistics centers, resulting in faster import-export processes.

Table 5. *Criteria set for logistic center development*

Main criteria	Subcriterias
A. Location	A1. Along the main roukes
	A2. Proximity and/or connectivity to seaports, airport and rail terminal
	A3. Proximity and/or connectivity to organized industrial centres
B. Infrustructure	B1. Multimodality
	B2. Warehouses and Bonded Warehouses
	B3. Offices and social facilities
	B4. Vehicle and equipment repair facilities
	B5. Telecommunications and information services
	B6. Car parks
	B7. Open storage areas
	B8. Land's ability to expand
C. Activities and services	C1. Loading and unloading opetarions
	C2. Custom services
	C3. Filling stations
	C4. Accommodation, restaurants and cafes
	C5. Banks and insurance services
	C6. Value added services
	C7. Security
D. Ownership and man.	D1. Public-private partnership
	D2. Owned and managed by private companies
	D3. Owned and managed by a public authority
E. Market conditions	E1. Logistics service providers' proficiency
	E2. Existing and potential business activities
	E3. Labour competence
	E4. Existing and integration of other logistic centres
F. Regulations	F1. Logistics centres should be managed by General Directorate for Logistics established under the Ministry of Transport
	F2. Regional logistics development plan should be set
	F3. Incentive and financial assistace programs offered by the goverment
	F4. Simple and efficient administration procedure for operating logistics centres
	F5. Low and simple tax system
G. Benefits	G1. Encourage and increase the combined transport
	G2. Operating cost reduction
	G3. Increase service quality and responsiveness
	G4. Increase in value-added activities related to logistics
	G5. Having and important role in regional/national development
	G6. Being environmental
H. Collaborations	H1. Project cooperations
	H2. Market cooperations
	H3. Joint use of infrastructure, bonded warehouses, equipments, warehouses
	H4. Joint purchasing of vehicle, equipment, fuel etc.
	H5. Sharing information
	H6. Cooperation on combining partial loads

Criterion D. Ownership and Management: This refers to the ownership of the area and the equipment and management model that are used to manage operations. The ownership and management models are defined as subcriteria. One of the private sector logistics center managers recommended private sector management by saying, "I do not think it is right to establish and manage logistics centers by the public because when the public is involved, things slow down. The public should support logistics centers by providing necessary services." However, TCDD expropriates or constructs logistics centers on its land. The TCDD investment program includes logistics centers, and expenditures are funded by appropriations. Leases are made through tenders when the private sector wants to invest in these logistics centers.

Criterion E. Market Conditions: This refers to the characteristics of the market that a logistics center serves. The market conditions that should be included in logistics centers are defined as subcriteria. The interviewees pointed out that the region should be considered when choosing the location of a logistics center, including its proximity to the organized industrial zones, the diversity of industrial activities, urbanization and planning decisions, and regional industrial development plans.

Criterion F. Regulations: This refers to the rules that regulatory agencies use to control, direct, or manage logistics centers. The managers frequently stated, "Turkey has no legislation for structuring logistic centers. We want this legislation to be included in the national transportation and logistics action plan. The bases of logistics center structuring must be regulated by law, and related regulations should be made as soon as possible."

Criterion G. Benefits: This refers to the benefits that logistics centers provide to all of their stakeholders. The benefits that logistics centers provide the most are defined as subcriteria. All of the managers who took part in the interview first mentioned the benefits of reducing costs. For example, one of the interviewees explained, "The most important advantages for logistics companies are that logistics centers reduce the costs of logistics companies and so increase their competitiveness. In addition, they improve their service quality and rapidness. Being operated in the logistic center allows them to interact and raise each other's standards. At the same time, companies can act together for a common will." The other one said, "Logistic centers contribute to the commercial potential and economic development of the region in which they are established, thereby contributing to the development of combined transport by increasing competition among companies operating in this region. Companies located in logistics villages can benefit from the

***Table 6.** Comparison of the main criteria*

Main criteria	Overall		Logistics centre managers		Logistics service providers		Logistics service buyers		Instutions	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
A. Location	0.218	1	0.237	1	0.115	4	0.367	1	0.191	2
B. Infrastructure	0.105	5	0.115	4	0.112	6	0.104	4	0.033	6
C. Activities and services	0.126	4	0.108	5	0.114	5	0.091	6	0.120	4
D. Ownership and management	0.057	8	0.080	6	0.049	8	0.066	7	0.031	7
E. Market conditions	0.202	2	0.211	2	0.258	1	0.174	2	0.191	2
F. Regulations	0.067	7	0.044	8	0.094	7	0.041	8	0.125	3
G. Benefits	0.168	3	0.171	3	0.182	2	0.100	5	0.249	1
H. Collaborations	0.101	6	0.073	7	0.121	3	0.107	3	0.102	5

following advantages: optimum vehicle planning (especially truck-to-truck), warehouses, a safe environment for all activities, single-sided management and planning, reduced transportation, industrial and personnel costs, a quality working environment, and extensive support services."

Criterion H. Collaborations: This refers to the different types of collaborations between logistics companies. The most common types of collaborations between logistics companies are defined as subcriteria. According to the managers, the logistics companies that operate in logistics centers cooperate in the following areas:

• Joint projects: If a company cannot afford to carry out a project alone, two or more companies can collaborate to complete the project.

• Joint purchases: This includes purchasing of vehicles, equipment, fuel, training, and information systems.

• Joint use of infrastructure and services: This includes warehouses, bonded warehouses, equipment, repair and maintenance services, bank and insurance services, and value-added services.

• Market expansion: When there is a demand for a market that the company normally don't serve, instead of rejecting the customer, they cooperate with the companies that already serve that market. By this way they extend their market.

• Partial loads are also combined.

They stated that the most common type of collaboration is market expansion. They want to increase their collaboration level but do not know how to address the issue of trust.

4.3. Findings from the Fuzzy AHP Analysis

A survey was sent to 20 experts that were divided into four groups: logistics center managers, logistics service providers, logistics service buyers, and institutions. There were 18 responses. The results of the fuzzy AHP calculations are displayed in Table 6 and Table 7 below. The Tables 6 and 7 show comparisons of the main criteria and subcriteria, as well as the total results and individual results for each respondent group.

First, the results of the **comparison of the main Criteria**, which include different judgments of the four respondent groups, are shown in Table 6. According to the final rankings, "**location**" appears to be the most important criterion, followed by "**market conditions**," with "**regulations**" and "**ownership and management**" receiving the lowest ranks. "**Infrastructure**," "**activities and services**," and "**ownership and management**" received moderate scores from the overall respondents. Second, the **subcriterion comparison** results are shown in Table 7.

5. Discussion

The results of this study revealed that there are eight main criteria that can be considered as a set of criteria for logistics center development, each with various subcriteria. These criteria directly affect the performance of logistics centers. To understand their priorities, a group of 18 experts from different stakeholder groups was asked to compare the main criteria and their subcriteria. Finally, the fuzzy AHP results are discussed below.

• Overall, the respondents and logistics service providers considered "**proximity and/or connectivity to seaports, airports, and rail terminals**" as the most important location subcriterion, with a significant weight of 60.5%. Intermodality is highly essential for attracting logistics service providers, which is currently a major challenge in the industry in Turkey. While logistics center managers and institutions are more concerned about logistics centers being close to load/existing and potential customers, logistics service buyers expect the logistics centers to be easily accessible.

Table 7. *Comparison of the Subcriteria*

Main criteria	Subcriterias	Overall		Logistics centre managers		Logistics service providers		Logistics service buyers		Instutions	
		Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
A. Location	A1. Along the main routes	0.377	2	0.124	2	0.260	2	0.529	1	0.108	3
	A2. Proximity and/or connectivity to seaports, airport and rail terminal	0.469	1	0.100	3	0.605	1	0.348	2	0.122	2
	A3. Proximity and/or connectivity to organized industrial centres	0.174	3	0.135	1	0.153	3	0.150	3	0.132	1
B. Infrustructure	B1. Multimodality	0.283	1	0.226	2	0.171	2	0.413	1	0.370	1
	B2. Warehouses and bonded warehouses	0.230	2	0.316	1	0.126	4	0.251	2	0.212	2
	B3. Offices and social facilities	0.056	6	0.039	7	0.064	7	0.047	6	0.060	6
	B4. Vehicle and equipment repair facilities	0.046	8	0.036	8	0.072	6	0.032	7	0.033	7
	B5. Telecommunications and information services	0.104	5	0.070	5	0.283	1	0.055	5	0.060	6
	B6. Car parks	0.055	7	0.063	6	0.063	8	0.028	8	0.062	5
	B7. Open storage areas	0.131	3	0.149	3	0.124	5	0.112	3	0.105	4
	B8. Land's ability to expand	0.130	4	0.129	4	0.138	3	0.093	4	0.127	3
C. Activities and services	C1. Loading and unloading operations	0.268	1	0.364	1	0.192	3	0.211	2	0.290	1
	C2. Customs services	0.255	2	0.287	2	0.147	4	0.404	1	0.291	2
	C3. Filling stations	0.041	7	0.037	6	0.063	7	0.027	7	0.028	7
	C4. Accommodation, restaurants and cafes	0.044	6	0.035	7	0.070	6	0.046	5	0.041	6
	C5. Banks and insurance services	0.061	5	0.040	5	0.073	5	0.044	6	0.058	5
	C6. Value added services	0.196	3	0.129	4	0.258	1	0.181	3	0.186	3
	C7. Security	0.170	4	0.142	3	0.234	2	0.129	4	0.135	4
D. Ownership and man.	D1. Public-private partnership	0.595	1	0.518	1	0.436	2	0.705	1	0.737	1
	D2. Owned and managed by private companies	0.323	2	0.384	2	0.453	1	0.241	2	0.215	2
	D3. Owned and managed by a public authority	0.105	3	0.117	3	0.131	3	0.092	3	0.072	3
E. Market conditions	E1. Logistics service providers' proficency	0.322	2	0.331	2	0.374	1	0.367	2	0.214	2
	E2. Existing and potential business activities	0.441	1	0.394	1	0.333	2	0.442	1	0.521	1
	E3. Labour competence	0.114	4	0.119	4	0.166	3	0.088	4	0.108	4
	E4. Existing and integration of other logistic centres	0.142	3	0.178	3	0.145	4	0.125	3	0.175	3

***Table 7.** continued*

Main criteria	Subcriterias	Overall		Logistics centre managers		Logistics service providers		Logistics service buyers		Instutions	
		Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
F. Regulations	F1. Logistics centres should be managed by General Directorate for Logistics established under the Ministry of Transport	0.053	5	0.055	5	0.054	5	0.045	5	0.035	5
	F2. Regional logistics development plan should be set	0.208	3	0.282	2	0.143	4	0.162	4	0.139	3
	F3. Incentive and financial assistace programs offered by the goverment	0.306	1	0.256	3	0.302	2	0.298	2	0.430	1
	F4. Simple and efficient administration procedure for operating logistics centres	0.184	4	0.142	4	0.222	3	0.188	3	0.106	4
	F5. Low and simple tax system	0.278	2	0.293	1	0.326	1	0.347	1	0.319	2
G. Benefits	G1. Encourage and increase the combined transport	0.128	4	0.134	5	0.104	6	0.148	3	0.116	4
	G2. Operating cost reduction	0.209	2	0.145	4	0.173	2	0.321	1	0.309	1
	G3. Increase service quality and responsiveness	0.218	1	0.183	2	0.172	3	0.302	2	0.223	2
	G4. Increase in value-added activities related to logistics	0.118	5	0.101	6	0.181	1	0.060	5	0.086	5
	G5. Increase cooperation between logistics companies	0.074	7	0.085	7	0.081	7	0.053	6	0.049	7
	G6. Having and important role in regional/national development	0.178	3	0.217	1	0.168	4	0.116	4	0.182	3
	G7. Being environmental	0.108	6	0.165	3	0.153	5	0.045	7	0.063	6
H. Collaborations	H1. Project cooperations	0.092	6	0.108	5	0.189	2	0.064	6	0.081	5
	H2. Market cooperations	0.236	2	0.183	2	0.263	1	0.204	2	0.288	2
	H3. Joint use of infrastructure, bonded warehouses, equipments, warehouses	0.187	3	0.160	4	0.151	5	0.178	3	0.119	3
	H4. Joint purchasing of vehicle, equipment, fuel etc.	0.122	4	0.174	3	0.099	6	0.090	4	0.066	6
	H5. Sharing information	0.117	5	0.081	6	0.162	4	0.075	5	0.118	4
	H6. Cooperation on combining partial loads	0.285	1	0.337	1	0.175	3	0.401	1	0.362	1

• **"Multimodality"** as an infrastructure subcriterion is a prerequisite for logistics centers because it received high rates from all the groups. **"Warehouses and bonded warehouses"** were ranked second, with problems in customs processes such as cost of customs and blockages in customs being one of the bottlenecks in Turkey's logistics sector. Bonded warehouses in logistics centers, in particular, can be an effective strategy for reducing problems in the customs process. The least important for all the groups appeared to be "**vehicle and equipment repair facilities**" and "**car parks**." Remarkably, the logistics service providers placed more importance on "**telecommunications and information services**" than the other groups. They strongly believe in the importance of technology, and the management of logistics centers should consider this belief.

• All the groups except logistics service providers believed that "l**oading and unloading operations**" and "**customs services**" are the most important subcriteria, with very high weights. The logistics service providers considered "**value-added services**" and "**security**" as the most important in contrast to the other groups. However, all the groups agreed that "**accommodations, restaurants, and cafes**" and "**filling stations**" were the least important.

• **"Public–private partnership"** is the most preferred ownership and management model for logistics centers. The logistics services providers preferred **"owned and managed by private companies."** All groups were against the public governance of logistics centers. Therefore, public support is required for financial and intermodal infrastructure investments during the establishment phase, but private sector management is preferred.

• Regarding the ranking of the market condition subcriterion, most of the respondents ranked "**existing and potential business activities**" as the most important, followed by "**logistics service providers' proficiency**." The "**existing and integration of other logistics centers**" and "**labor competence**" criteria were ranked as the least important. The preferences of the logistics service providers differed slightly from those of the other groups in that they ranked the "**logistics service providers' proficiency**" first and ranked "**existing and potential business activities**" second. They also placed a higher value on "**labor competence**" than the other groups.

• All the groups mostly agreed on the prioritizing of the regulation subcriterion. The managers of the logistics centers governed by central management under the Ministry of Transport strongly objected as they expect the government to promote logistics centers by incentives, financial assistance, and a low and simple tax system. The most important criterion was "**incentive and financial assistance programs offered by the government**." Actually, three groups ranked "**low and simple tax system**" first, and its weight was slightly lower than that of "incentive and financial assistance programs offered by the government."

• The most significant opinion differences between the groups were observed in the benefit subcriteria. The following points can be noted: overall, the results demonstrated that the most important benefit of logistics centers is "**increase service quality and responsiveness**," followed by "**operating cost reduction**," with total weights of 42% among seven subcriteria. "**Increase service quality and responsiveness**" and "**operating cost reduction**" were important for all groups, particularly for logistics service buyers, with a total weight of 62%. The least important benefit subcriteria were "**being environmental**" and "**increase collaborations between logistics companies**." The logistic center managers believed that the most important benefit was "**having an important role in regional/national development**," while the logistics service providers believed it was "**increase in value-added activities related to logistics**," and finally, the logistics service buyers believed it was "**operating cost reduction**." The largest difference was observed in the "**increase in value-added activities related to logistics**," which was the most important benefit for the logistics service providers but ranked sixth for the logistics center managers and fifth for the other groups.

• According to the respondents, logistics centers reduce operating costs and increase service quality. The majority of the stakeholders believed that **"collaboration on combining partial loads"** was the most important collaboration type, while "**market collaborations**" was considered the second most important, with a total weight of 53%. "**Sharing information**" and "**project collaborations**" were the least important among the six subcriteria. Noticeably, three groups (logistics center managers, logistics service buyers, and instructions) had similar overall results, but the ranking of logistics service providers differed from that of others. Logistics service providers ranked "**market collaborations**" and "**project collaborations**" as the most important collaboration types, with a total weight of 45%. They ranked "**joint purchasing of vehicle, equipment, fuel, etc**." as the least important. The logistics service buyers placed more importance on "**collaborations on combining partial loads**," which they weighted at 40%.

6. Conclusions

This research aimed to determine and prioritize a set of criteria for the development of logistic centers in Turkey. Data were gathered using both qualitative and quantitative methods. The qualitative research method revealed eight main criteria with their subcriteria. The fuzzy AHP was used for ranking and was conducted with 18 professionals/experts from four different groups of logistics center stakeholders: logistics service providers (5 experts), logistics center management (5 experts), logistics service buyers (4 experts), and institutions (4 experts).

Since the early 2000s, both the government and the private sector in Turkey have initiated logistics center projects, with some still in progress. State (TCDD) logistics centers are mainly responsible for the consolidation and deconsolidation of incoming and outgoing freights in the railways they serve. Thus, they should be considered as "intermodal terminals" rather than logistics centers. Intermodal terminals, as defined by the United Nations Economic and Social Council, connect at least two transport modes, which are usually road and rail, and they are less complex than logistics centers. When the TCDD logistics center plans a project, it considers the logistics potential of a region, the land-rail-air-maritime transportation possibilities, and the proximity to the OIZ and industrial areas. The first-stage railway investments are made in the logistics centers, and rail transport warehouses are formed. The lands of the logistic centers are either expropriated by TCDD or built on TCDD's land. The TCDD investment program includes logistics centers, and expenditures are funded by appropriations. When the private sector wants to invest in these logistics centers, leasing transactions are made through tenders. There is no specific legislation on logistics centers, which the interviewees strongly criticized. However, there are different types of private sector logistics centers, and the first one to open was the Ankara Logistics Center, which can be classified as a logistics center with many features. The Ankara Logistics Center delivers most of the products produced in Ankara to their final destination. The center creates added value for shippers and logistics companies through the various actors (public institutions, customs units, association and union representatives, and universities) that are located in the center. However, intermodality, which is one of the most important infrastructure features, is missing. The Ankara Logistics Center does not yet have a railway connection.

In terms of quality and quantity, Turkey's logistics center development lags behind that of the rest of the world. There are 240 logistic centers in the EU, and most of them are located along TEN-T. Most of these centers are located in central Europe, including Germany (35), Spain (33), France (26), and Italy (21). The largest logistics center in Germany has 600 ha (GVZ Leipzig), while the average size of logistics centers is 175 ha. The logistics centers in Germany are all public-private partnerships and have railway connections. There are many logistics centers in Asia, from China to Dubai, and their distinguishing features are advanced intermodality, simple customs procedures, and intensive information technology usage. All logistics clusters in the United States of America are linked by intermodal infrastructure. The TCDD logistics center has a small scale (average of 50 ha) and functions more like an intermodal transfer terminal. In general, activities and services, such as customs clearance, closed warehouse areas, offices, and repair maintenance areas, are below expectations. The Ankara Logistics Center covers 70 ha and possesses the typical characteristics of a logistics center, including the ability to expand. The MOS Logistics Center in Manisa is 32 ha in size. It is in an organized industrial zone and has a rail connection to the port. However, in terms of activities and services, it functions more like an intermodal transfer terminal, similar to the TCDD logistics centers. Logistics companies, particularly small- and medium-sized ones, need to be educated about logistics centers and become aware of them. Institutions should put extra effort to make this awareness possible, and public authorities should provide tax favors and incentives to promote logistics centers. Otherwise, the logistics sector in Turkey will be unable to compete internationally, and intermodality and transit trade will remain unimproved.

This research has some limitations. Benchmarking logistics centers in Turkey and other parts of the world would be beneficial, but this is not possible because of financial and physical constraints. Instead, logistics center formations in different continents have been solely based on the literature, reports, and institutions. Another limitation is the formation of logistics centers, which is a relatively new development in Turkey. Thus, there are not many facilities that actually function as "logistics centers." TCDD has nine logistics centers in operation, but they operate more like intermodal terminals.

Future research could examine if the determined and prioritized criteria set for logistics center development are fulfilled by advanced/successful logistics centers around the world.

Authorship Contributions

Concept design: D. Çavuşoğlu, Y. Zorba, S. Esmer, Data Collection or Processing: D. Çavuşoğlu, Analysis or Interpretation: D. Çavuşoğlu, Y. Zorba, S. Esmer, Literature Review: D. Çavuşoğlu, Writing, Reviewing and Editing: D. Çavuşoğlu, Y. Zorba.

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An Optimized Routing Procedure for Safe Navigation of Large Tankers in the Strait of Istanbul

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Abstract

The risks associated with the navigation of large tankers in restricted waterways have resulted in continuing development of routing measures such as Traffic Separation Schemes (TSS). This is generally subject to discussion between the administration and ship operators which may find some navigational rules and regulations unnecessarily restrictive. Motivated by the need for an objective and scientific method to determine the vessel characteristics and environmental conditions for a safe passage through a restricted waterway, this paper presents an optimized routing procedure based on maneuvering simulations and non-linear direct search techniques which can be used to determine the best attainable route for large tankers in restricted waterways and specified environmental conditions. The mathematical model for predicting the maneuvering performance is based on a modular approach in which the hydrodynamic, propeller and rudder forces are computed separately, while environmental forces are estimated by semi-empirical methods. The objective of the optimization procedure is to determine the required number and magnitude of rudder control commands for remaining within a specified TSS and minimizing a grounding or collision possibility.

Keywords: Ship maneuvering, Route optimization, Traffic separation scheme, Strait of Istanbul

1. Introduction

Transportation of crude oil and refined petroleum products by tankers between production sites, refineries and points of consumption accounts for nearly a 30% of global [1]. These tankers are classified by their deadweight tonnage and the scale of economy dictates that the capacity should be as large as possible provided that there is adequate cargo oil to fill the tanks and sufficient loading/unloading facilities. As economic concerns resulted in classes of large tankers, the number of accidents, mainly due to the collision and grounding in restricted waterways, have created significant environmental, safety and financial risks [2]. Considering the environmental consequences, there is a possibility of damage to soil, water, air, and all living things in the ecosystem as a result of tanker accidents [3]. Also, safety is a crucial concern in securing the crew and passenger's lives as accidents lead to injury and, worse, loss of life [4]. From a financial point of view, these collisions can lead to unavoidable delays and reduction of profits [5]. These risks are not only associated with tanker size and cargo capacity but also strongly related to navigational conditions, environmental conditions, and crew competence. In studies where past tanker accidents were examined by risk analysis methods, navigation-based errors were expressed with sub-segments such as inefficient use of bridge navigation equipment, inappropriate route selection, and procedure failure [6]. Environmental factors are uncontrollable and can be considered as external effects such as weather conditions, traffic speed and density [7]. Besides, crew competence was examined in many studies within the context of the human factor, and it was revealed that competition in training, critical decision-making skills, and language skills can cause problems at sea [8,9]. In order to ease the problem, International Maritime Organization established vessel traffic control systems including traffic routing schemes, shipping lanes, speed limitations, etc. [10]. Traffic Separation Schemes (TSS) consisting of regulated traffic lanes indicating the traffic directions, turning-points,

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deep-water lanes, and separation zones between the main traffic lanes have proven to be very successful in preventing collisions and groundings in restricted waterways. Within the TSS the risk of collision or grounding will be reduced by avoiding the body of water between two opposite lanes and between the lane and the shoreline, respectively.

TSS is implemented to regulate shipping through the Turkish straits, consisting of the strait of Istanbul and the strait of Çanakkale since 1994 [2]. The Maritime Traffic Regulations for the Turkish Straits and the Marmara Region were revised in 1998 [11]. These instructions regulated the suspension of all traffic in conditions of poor visibility, the implementation of one-way traffic during the transit of certain types of vessels and the restriction of large vessels carrying hazardous cargo to daylight-only transit. It is assumed that some vessels because of their type, size or maneuvering characteristics could not navigate safely within the TSS. In the regulations, a vessel with restricted ability to maneuver in the TSS is defined as a vessel 150 meters in length or more carrying dangerous cargo such as crude oil. It should also be noted that ships that will be subject to additional rules for safe passage of the strait are defined as ships with an overall length of 300 meters and above, and misunderstandings can lead to dangerous situations and even accidents in the Turkish straits. The passage of such vessels is restricted to permitted daylight hours and they are not allowed to be in the straits at the same time in the opposite directions. Periods of poor weather also exacerbate the problem by further restricting passage within the permitted hours. So, significant delays are inevitable for transportation on restricted seaways. Also, the overcrowding of anchorages at the ends of the Strait of Istanbul, increasing the risk of collisions.

The length classification is mainly based on the pilot experiences and has been a matter of discussion between the ship operators and the regulatory bodies. For example, based on the experience of its members OCIMF [12] suggests that the Suezmax class tanker of 275 meters has the maximum size which can safely navigate the Strait of Istanbul with acceptable margins. Clearly, analytical techniques need to be developed for the navigational safety of large vessels in restricted waterways. Sariöz and Narli [13] used a real-time ship maneuvering simulation to assess the behavior of large vessels in a TSS under external forces. It was shown that depending on the ship master's skill and experience the maneuvering behavior of the vessel may differ significantly. This raises the question of whether a set of optimum engine and rudder control commands exist for a safe passage through a specified TSS for given environmental conditions. A simulation-based optimization method is developed by Gucma [14] for safe entering of bulk carriers with a 300-meter length for a specific commercial port. In order to improve safety in navigation, more followed work was done for hydrodynamic interaction of vessels in constrained waterways. Lee et al. [15] determined the minimum safe distance between two vessels and speed limitations numerically for a curved narrow channel. Shu et al. [16] also analyzed automated identification system data collected for a port to investigate the effects of not only ship encounters but also external factors on ship behavior. According to the typical maneuvers involved at confined waterway, Du et al. [17] proposed a numerical tool to investigate the maneuvering characteristics. Based on identified hydrodynamic coefficients, the authors indicated that fitting formulas are required to describe the turning phenomenon. In a restricted two-way waterway, Liu et al. [18] carried out a comprehensive traffic simulation model to be a guide to improve the efficiency in ship traffic. In the study, which stated that ship speed and channel length are the most critical factors, features such as navigational rules and interaction between ships were also included in the model. Another Very Large Crude Carriers (VLCC) maneuvering simulation through the strait of Istanbul was simulated by Bayezit et al. [19] to express the safety of autopilot mode. In the study, the one-way passage was examined and although the voyage was generally safe in the Strait of Istanbul, it was revealed that the controller parameters should be optimized to be successful in critical areas. VLCC models were also investigated in maneuvering performance perspective with different mathematical models [20]. As a result of the study, it is stated that the Maneuvering Modeling Group (MMG) model-based third-order polynomial has an advantage in terms of determining the maneuver characteristics.

In the simplest meaning, an optimization problem for ship routing consists of determining a proper value of a function by systematically selecting control parameters from within a set. Setting up a rational and accurate ship routing system by means of optimization procedures is important to provide effective management in navigation routes, and to determine traffic separation lanes. In the present paper, an optimized routing procedure based on ship maneuvering simulations and non-linear direct search techniques to yield an optimum set of propeller/rudder control commands for a safe passage through a specified TSS is presented. The maneuvering simulation procedure, as described in Section 2, is based on a modular mathematical model in which hydrodynamic forces, propeller and rudder forces and the environmental effects are estimated in separate modules. Then, the non-linear equations of motion are solved in the time domain to predict the vessel trajectory for given engine RPM, rudder angle under specified conditions.

In order to validate the mathematical model, a typical VLCC designed by KRISO which is referred to as KVLCC2 by SIMMAN workshops was selected as a benchmark case [21]. The reason for focusing on the oil tanker in the current study is that oil tanker operations are extremely critical due to having potential risks. The collision or grounding of oil tankers has the greatest risks of fires or explosions, air pollution, and such environmental damages. Obviously, many ship types, including bulk carriers and container ships, use the Istanbul strait on a regular basis, in addition to oil tankers. It is expected that similar results would be obtained with different ship types of similar dimensions and sizes.

In Section 3, the turning and zig-zag tests were simulated and compared with the full-scale test results. Section 4 presents a numerical optimization procedure to determine the rudder control commands required for a safe passage through the lanes of the TSS established at the Straits of Istanbul. The procedure is based on an inverse approach: The maneuvering theory is recast in terms of the performance criteria defined as the deviation from a specified trajectory. Here, the propeller revolutions and the rudder angles are the values of the ship maneuvering control parameters.

2. Mathematical Maneuvering Model

The behavior of a vessel navigating in a seaway in the presence of wind, waves and current can be represented by a set of coupled non-linear differential equations in six degrees of freedom. However, for large vessels such as VLCC's the primary motions can be considered to take place in the horizontal plane and the heave, pitch and roll motions may be ignored, particularly in restricted waterways where the wave conditions are not severe.

The Earth-fixed and the body-fixed reference frames are shown in Figure 1. The origin of the body-fixed reference frame is located at the mid-ship and the x and y axes correspond to the longitudinal and lateral direction of the vessel, respectively. The ship's center of gravity is located at $(x_{OG}, y_{OG}, 0)$ in the system of coordinates. The path of the vessel is defined as the trajectory traced by the centre of gravity. Heading refers to the direction (ψ, yaw angle) of the ship's longitudinal axis with respect to the Earth-fixed longitudinal axis. The difference between the heading and the actual course (or direction of the velocity vector at the center of gravity) is the drift angle, β.

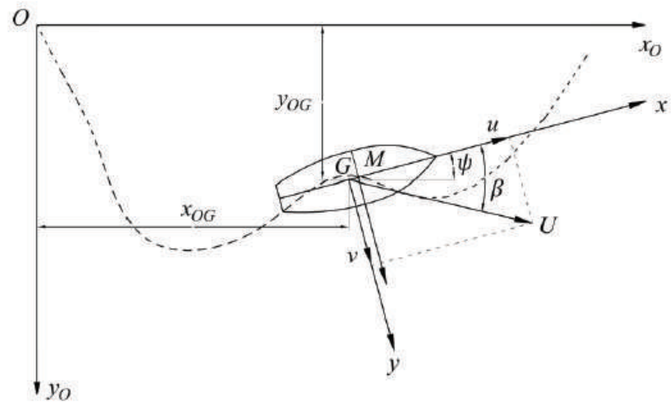

Figure 1. *Earth-fixed and ship-fixed coordinate systems*

The equations of motion for a ship moving in the horizontal plane with respect to a body-fixed reference frame can be derived as follows by using Newton's equation of motion;

$$\begin{aligned} &\text{Surge} \quad m\left(\dot{u} - vr - x_{OG}r^2\right) = X_H + X_P + X_R + X_{EXT} \\ &\text{Sway} \quad m\left(\dot{v} + ur + x_{OG}\dot{r}\right) = Y_H + Y_P + Y_R + Y_{EXT} \\ &\text{Yaw} \quad I_z\dot{r} + m x_{OG}(\dot{v} + ur) = N_H + N_P + N_R + N_{EXT} \end{aligned} \qquad (1)$$

where

m : mass of the ship

u, v : ship velocities in x and y axes

$\dot{u}$, $\dot{v}$: ship accelerations in x and y axes

r, $\dot{r}$: yaw rate and acceleration

I_z : mass moment of inertia about vertical axis through the centre of gravity

X, Y : surge and sway forces about longitudinal and lateral axes

N : yaw moment about vertical axis through the centre of gravity

H, P, R, EXT : subscripts indicating hull, propeller, rudder and external forces

This mathematical model is based on the concept of modularity which is achieved by isolating the forces exerted on the ship by the hull and appendages, rudder(s), propeller(s) and external forces. The basic mathematical modules required to solve the equations of motion for typical large surface vessels are related to the following:

• Hydrodynamic forces due to the hull and appendages (X_H, Y_H, N_H),

- Propulsion forces due to the propellers and thrusters (X_P, Y_P, N_P),
- Forces due to control surfaces like rudder and fins (X_R, Y_R, N_R),
- Forces due to the environmental disturbances such as wind, current and waves (X_{EXT}, Y_{EXT}, N_{EXT}).

2.1. Hydrodynamic Forces due to the Hull and Appendages

The prediction of hydrodynamic forces on a maneuvering vessel is a complex problem due primarily to the complications of viscous and free-surface effects. It will be assumed that the disturbance of free surface is sufficiently small and the hydrodynamic forces at any instant depend only on the prevailing instantaneous velocities and accelerations of the ship. Then, the hydrodynamic forces due to the hull and appendages can be considered as sum of two main components:

- Added mass and moment (inertia) components due to the motion in an ideal fluid with no circulation,
- Viscous damping force and moment components accounting primarily for viscous dissipative losses of a maneuvering ship.

2.1.1. Added Mass and Moment Components

The added mass and moment (inertia) components are important at the initial and transient parts of the ship maneuvering but the contribution of these terms in the steady or near steady part of the turning maneuver is small. Since the added mass and moment are assumed to be essentially the result of the inertia of the fluid they can be estimated using potential theory as a function of the hull geometry and the fluid density. The complete set equations for added mass and moment components can be simplified by assuming that there is no significant interaction between viscous and inertia properties of the fluid, and the second or higher order acceleration terms can be neglected. It may also be assumed that terms representing cross-coupling between acceleration and velocity parameters are zero or negligibly small, and forces and moments have appropriate port and starboard symmetry. Then the added mass and moment components can be expressed as follows:

$$X_I = \frac{\rho}{2} L^3 (X'_{\dot{u}} \dot{u})$$

$$Y_I = \frac{\rho}{2} L^4 (Y'_{\dot{r}} \dot{r}) + \frac{\rho}{2} L^3 (Y'_{\dot{v}} \dot{v}) \tag{2}$$

$$N_I = \frac{\rho}{2} L^5 (N'_{\dot{r}} \dot{r}) + \frac{\rho}{2} L^4 (N'_{\dot{v}} \dot{v})$$

The coefficients in these equations are known as the hydrodynamic/maneuvering derivatives. Typical examples of empirical methods to estimate the coefficients are presented below:

$$X'_{\dot{u}} = 0.55\, C_B \frac{B}{L} Y'_{\dot{v}}$$

$$Y'_{\dot{v}} = -\pi \left(\frac{T}{L}\right)^2 \left[1 + 0.16 \frac{C_B B}{T} - 5.1 \left(\frac{B}{L}\right)^2\right]$$

$$Y'_{\dot{r}} = -\pi \left(\frac{T}{L}\right)^2 \left[0.67 \frac{B}{L} - 0.0033 \left(\frac{B}{T}\right)^2\right] \tag{3}$$

$$N'_{\dot{v}} = -\pi \left(\frac{T}{L}\right)^2 \left[1.1 \frac{B}{L} - 0.041 \frac{B}{T}\right]$$

$$N'_{\dot{r}} = -\pi \left(\frac{T}{L}\right)^2 \left[\frac{1}{12} + \frac{1}{60} \frac{C_B B}{T} - \frac{1}{3} \frac{B}{L}\right]$$

given by [22], and [23], where, L, B, T and C_B represent the length, breadth, draught and the block coefficient of the vessel, respectively.

2.1.2. Viscous Damping Force Components

Viscous damping forces, due to the viscous dissipative losses, affect the flow around a maneuvering vessel in two distinct ways. At small drift angles, the ship can be viewed as a low aspect ratio lifting surface in the lateral plane, with the assumption that the lift force develops with the circulatory flow. At larger drift angles, a significant part of the forces is due to the cross-flow drag which is not linearly related to drift and yaw angle velocities. In typical ship maneuvering problems, both circulatory and cross-flow forces are present and equally important in all stages of a manoeuver. A convenient way of expressing viscous hydrodynamic forces is to employ a Taylor expansion consisting of linear and 3rd order components as follows:

$$X_V = \frac{\rho}{2} L^4 \left(X'_{rr} r^2 \right) + \frac{\rho}{2} L^3 (X'_{vr} vr) + \frac{\rho}{2} L^2 (X'_{vv} v^2)$$

$$Y_V = \frac{\rho}{2} L^4 (Y'_{rrr} r^3) + \frac{\rho}{2} L^3 (Y'_r ur + Y'_{vvr} vvr + Y'_{vrr} vrr) + \frac{\rho}{2} L^2 (Y'_v uv + Y'_{vvv} v^3) \tag{4}$$

$$N_V = \frac{\rho}{2} L^5 (N'_{rrr} r^3) + \frac{\rho}{2} L^4 (N'_r ur + N'_{vvr} vvr + N'_{vrr} vrr) + \frac{\rho}{2} L^3 (N'_v uv + N'_{vvv} v^3)$$

Typical semi-empirical formulae for estimating the linear viscous hydrodynamic force coefficients are presented by [23]:

$$\begin{aligned} Y'_v &= -\pi\left(\frac{T}{L}\right)^2\left[1+0.4\frac{C_B B}{T}\right] \\ Y'_r &= \pi\left(\frac{T}{L}\right)^2\left[\frac{1}{2}-2.2\frac{B}{L}+0.08\frac{B}{T}\right] \\ N'_v &= -\pi\left(\frac{T}{L}\right)^2\left[\frac{1}{2}+2.4\frac{T}{L}\right] \\ N'_r &= -\pi\left(\frac{T}{L}\right)^2\left[\frac{1}{4}+0.039\frac{B}{T}-0.56\frac{B}{L}\right] \end{aligned} \tag{5}$$

The empirical methods to estimate the non-linear maneuvering derivatives is limited comparing to linear ones due to the complexity. The preferred methods, expressed in [22], are given as follows:

$$\begin{aligned} X'_{vv} &= 12\left\{0.07\left(\frac{B}{L}\right)^2\frac{T}{L}\left[1+0.8\left(\frac{T}{B}\right)\right]^2\right\} \\ X'_{vr} &= C_B Y'_{\dot{v}}\left[1+0.28\left(1.7-\sqrt{\frac{C_B B}{T}}\right)\right] \\ X'_{rr} &= -0.07\left(\frac{B}{L}\right)^2\frac{T}{L}\left[1+0.8\left(\frac{T}{B}\right)\right]^2 \\ Y'_{vrr} &= Y'_v/2.5 \\ N'_{vrr} &= 0.5N'_v \end{aligned} \tag{6}$$

The remaining unknown variables are expressed by [24] as follows.

$$\begin{aligned} Y'_{vvv} &= -\left(1.281\frac{T}{L}+0.031\right) \\ Y'_{vvr} &= 0.628\frac{C_B B}{L}-0.066 \\ Y'_{rrr} &= 0.029\frac{C_B B}{L}-0.004 \\ N'_{vvv} &= 0.188\frac{T}{L}-0.01 \\ N'_{vvr} &= 0.178\frac{C_B B}{L}-0.037 \\ N'_{rrr} &= -\left(0.014\frac{C_B B}{L}-0.002\right) \end{aligned} \tag{7}$$

The total hydrodynamic force components are represented by the summation of the inertia and viscous terms:

$$\begin{aligned} X_H &= \frac{\rho}{2}L^4 X'_{rr}r^2+\frac{\rho}{2}L^3\left(X'_{\dot{u}}\dot{u}+X'_{vr}vr\right)+\frac{\rho}{2}L^2\left(X'_{vv}v^2\right) \\ Y_H &= \frac{\rho}{2}L^4\left(Y'_{\dot{r}}\dot{r}+Y'_{rrr}r^3\right)+\frac{\rho}{2}L^3\left(Y'_{\dot{v}}\dot{v}+Y'_r ur+Y'_{vvr}vvr+Y'_{vrr}vrr\right)+\frac{\rho}{2}L^2\left(Y'_v uv+Y'_{vvv}v^3\right) \\ N_H &= \frac{\rho}{2}L^5\left(N'_{\dot{r}}\dot{r}+N'_{rrr}r^3\right)+\frac{\rho}{2}L^4\left(N'_{\dot{v}}\dot{v}+N'_r ur+N'_{vvr}vvr+N'_{vrr}vrr\right)+\frac{\rho}{2}L^3\left(N'_v uv+N'_{vvv}v^3\right) \end{aligned} \tag{8}$$

The equations of motion can be written as below with all of the acceleration-related terms placed in the left-hand side and all the other terms placed in right-hand side.

$$\begin{aligned} \left(m-\frac{\rho}{2}L^3X'_{\dot{u}}\right)\dot{u} &= F_X(v,r) \\ \left(m-\frac{\rho}{2}L^3Y'_{\dot{v}}\right)\dot{v}+\left(m\,x_{OG}-\frac{\rho}{2}L^4Y'_{\dot{r}}\right)\dot{r} &= F_Y(u,v,r) \\ \left(m\,x_{OG}-\frac{\rho}{2}L^4N'_{\dot{v}}\right)\dot{v}+\left(I_z-\frac{\rho}{2}L^5N'_{\dot{r}}\right)\dot{r} &= F_N(u,v,r) \end{aligned} \tag{9}$$

where

$$\begin{aligned} F_X(v,r) &= \frac{\rho}{2}L^2X'_{vv}v^2+\left(m+\frac{\rho}{2}L^3X'_{vr}\right)vr+\left(m\,x_G+\frac{\rho}{2}L^4X'_{rr}\right)r^2 \\ F_Y(u,v,r) &= \frac{\rho}{2}L^4\left(Y'_{rrr}r^3\right)+\left(\frac{\rho}{2}L^3Y'_r-m\right)ur+\frac{\rho}{2}L^3\left(Y'_{vvr}vvr+Y'_{vrr}vrr\right)+\frac{\rho}{2}L^2\left(Y'_v uv+Y'_{vvv}v^3\right) \\ F_N(u,v,r) &= \frac{\rho}{2}L^5\left(N'_{rrr}r^3\right)+\left(\frac{\rho}{2}L^4N'_r-m\,x_G\right)ur+\frac{\rho}{2}L^4\left(N'_{vvr}vvr+N'_{vrr}vrr\right)+\frac{\rho}{2}L^3\left(N'_v uv+N'_{vvv}v^3\right) \end{aligned} \tag{10}$$

These system of ordinary differential equations can be presented in the following standard form:

$$\begin{bmatrix} m-\frac{\rho}{2}L^3X'_{\dot{u}} & 0 & 0 \\ 0 & m-\frac{\rho}{2}L^3Y'_{\dot{v}} & m\,x_G-\frac{\rho}{2}L^4Y'_{\dot{r}} \\ 0 & m\,x_G-\frac{\rho}{2}L^4N'_{\dot{v}} & I_z-\frac{\rho}{2}L^5N'_{\dot{r}} \end{bmatrix}\begin{bmatrix}\dot{u}\\ \dot{v}\\ \dot{r}\end{bmatrix} = \begin{bmatrix} F_X(v,r)\\ F_Y(u,v,r)\\ F_N(u,v,r)\end{bmatrix} \tag{11}$$

The solution of the equation yields the surge, sway, and yaw accelerations. The longitudinal and lateral velocity components and the yaw rate can be obtained by the following integrations with respect to time:

$$u(t)=\int_0^t\dot{u}(t)dt\ ;\ v(t)=\int_0^t\dot{v}(t)dt\ ;\ r(t)=\int_0^t\dot{r}(t)dt \tag{12}$$

The velocity components in a global coordinate system can be obtained through the following transformation:

$$\begin{aligned} \dot{x}(t) &= u(t)\cos\psi(t) - v(t)\sin\psi(t) \\ \dot{y}(t) &= u(t)\sin\psi(t) + v(t)\cos\psi(t) \end{aligned} \tag{13}$$

where $\psi(t)$ is the yaw angle which can be obtained by the integration of yaw rate with respect to time:

$$\psi(t) = \int_0^t r(t)dt \tag{14}$$

The coordinates of the center of gravity of the vessel defines the trajectory.

$$x(t) = \int_0^t \dot{x}(t)dt \quad ; \quad y(t) = \int_0^t \dot{y}(t)dt \tag{15}$$

2.2. Propeller Forces

The propellers operate in a complex flow field at the stern of the ship. The exact numerical simulation of the interaction between the current due to the presence of the propeller and the flow through the propeller requires powerful computational resources. Therefore, most propeller design and analysis applications are also carried out by establishing more practical flow models. Also, prediction of the propeller forces is important for maneuvers and indirectly for rudder force modelling. The propeller produces a thrust in the negative x-direction in Earth-fixed coordinate system. This force can be non-dimensionalized by the nominal rotational speed *nD* and propeller net thrust force may be represented by

$$X_P = (1-t)\rho\, n_P^2 D_P^4 K_T(J_P) \tag{16}$$

where t is the thrust deduction fraction, n_P the propeller rotational rate and D_P the propeller diameter. The thrust coefficient, $K_T(J_P)$, can be estimated by using the open water test measurements of the propeller in terms of the advance number, J_P, which is expressed as:

$$J_P = \frac{u_P}{n_P D_P} = \frac{u(1-w_P)}{n_P D_P} \tag{17}$$

where u is the axial ship velocity and w_P is the Taylor wake fraction for the propeller behind the ship hull. For a manoeuvring vessel the following empirical formula is developed for estimating w_P based on model test data [25]:

$$w_P = w\exp\left(K_1 \beta_P^2\right) \tag{18}$$

where w is the wake fraction value is based on an average longitudinal velocity at the propeller for a ship in straight ahead motion and $K_1 = -4.0$ is a constant. The geometrical inflow angle at propeller position is defined as,

$$\beta_P = \beta - x'_P r' \tag{19}$$

where β is the drift angle, x'_P is the non-dimensionalized longitudinal location of the propeller by $x\,p/L$, and r' is the non-dimensionalized yaw rate by rL/U.

Values of the thrust deduction fraction (t) and the wake fraction (w) for various types of ship hulls and propellers in ahead motion are normally determined from model test data, with appropriate corrections for scale effects in order to apply the results to full-scale ships. When the experimental data are not available semi-empirical method of [26] may be used for estimating the coefficients.

2.3. Rudder Forces

The components of the hydrodynamic forces acting on the rudder are essentially in the same category as for a ship hull, also the interaction with the propeller slipstream and the effective angle of attack should be fully taken into account. For large single screw/rudder vessels, such as VLCCs the standard MMG formulation has been shown to correlate well with the experimental and full-scale test results [27]. The surge force, sway force, and yaw moment generated by the rudder are respectively expressed as:

$$\begin{aligned} X_R &= -F_N \sin\delta \\ Y_R &= -(1+a_H) F_N \cos\delta \\ N_R &= -(x_R + a_H x_H) F_N \cos\delta \end{aligned} \tag{20}$$

where x_R is the x-coordinate of the centre of lateral force and δ is the rudder angle. The position of additional lateral force, x_H, is taken as $-0.45L_{BP}$. The a_H coefficient is the rudder force increase factor and can be estimated as a function of the block coefficient as follows:

$$a_H = 0.62(C_B - 0.6) + 0.227 \tag{21}$$

The normal force on the rudder, F_N, can be approximated as

$$F_N = \frac{\rho}{2}\frac{6.13\lambda}{\lambda + 2.25} A_R U_R^2 \sin\alpha_R \tag{22}$$

where A_R is the rudder area and λ is the rudder aspect ratio. The rudder inflow speed and angle are defined as follows:

$$U_R = \sqrt{u_R^2 + v_R^2}$$
$$\alpha_R = \delta - \tan^{-1}\left(\frac{v_R}{u_R}\right) \cong \delta - \frac{v_R}{u_R} \qquad (23)$$

The longitudinal inflow velocity component, u_R can be estimated by use of the axial momentum theory for an actuator disk.

$$u_R = \varepsilon u_A \sqrt{\eta \left[1 + K_M\left(\sqrt{1 + \frac{8}{\pi}\frac{K_T}{J_P^2}} - 1\right)\right]^2 + (1 - \eta)} \qquad (24)$$

where u_A is the speed of advance, η is the ratio of propeller diameter to rudder span, K_M is a function of the axial position of the rudder relative to the propeller and it equals 0.5 at the point on the propeller centre and 1.0 at infinity for downstream. K_T is the thrust coefficient, and J is the advance constant. The function ε represents the ratio of wake fraction at rudder position to that at the propeller position where w_P is the wake fraction at propeller and w_R is the wake coefficient at rudder position.

$$\varepsilon = \frac{1 - w_R}{1 - w_P} \qquad (25)$$

The lateral inflow velocity component in the, v_R can be expressed as follows:

$$v_R = U\gamma \beta_R \qquad (26)$$

where U is the resultant ship speed, γ is the flow rectifying effect and β_R is the effective inflow angle to rudder. The flow rectifying effect due the ship's hull and the propeller can be expressed as [25],

$$\gamma = C_P C_S \qquad (27)$$

The propeller flow-rectification coefficient, C_P, is given in the following form:

$$C_P = 1/\sqrt{1 + 0.6\eta(2 - 1.4s)s/(1 - s)^2}\ ,$$
$$s = 1 - u(1 - w_P)/n_P P \qquad (28)$$

where P is the propeller pitch ratio. The ship flow-rectification coefficient, C_S, is given in the following form:

$$C_S = \begin{cases} K_3 \beta_R & for\ \beta_R \leq C_{SO}/K_3 \\ C_{SO} & for\ \beta_R > C_{SO}/K_3 \end{cases} \qquad (29)$$

with K_3 = 0.45 and C_{SO} = 0.5. The effective inflow angle to rudder, β_R is defined as follows:

$$\beta_R = \beta - 2x'_R r' \qquad (30)$$

where β is the hull drift angle, x'_P non-dimensionalized longitudinal position of the rudder by x_R/L, and r' the dimensionalized yaw rate by rL/U.

2.4. External Forces

Many types of external forces may affect the maneuvering performance of a ship such as wave, wind and current forces, bank effects, ship-ship interaction, mooring lines, fender forces and anchor forces, and wave forces. Within the context of the present study only the current effects, the wind and waves forces are considered.

2.4.1. Current Effects

The current forces depend on the absolute velocity and the direction of current as well as the vessel velocity. The relative current velocity components in the longitudinal and transverse directions through the water is expressed by:

$$U_{Cx} = U_C \cos\alpha_C - u$$
$$U_{Cy} = U_C \sin\alpha_C - v \qquad (31)$$

where

U_C : absolute current velocity

α_C : current direction with respect to Earth-fixed coordinate system

u, v : velocity components of ship in x and y directions

2.4.2. Wind Forces

There are various empirical methods that can be used to determine wind loads [28]. In the first of these methods [28], empirical formulas giving the transverse and longitudinal wind forces and wind moment were derived by analyzing the results of the experiments with different types of commercial ship models in different model test laboratories. Besides, in the study of [29] transverse and longitudinal wind cross-sectional areas are included in the wind force components and wind moment calculations. In the proposed method for offshore platforms [30], the cross-sectional area exposed to the wind includes all elements above the waterline such as the superstructure, crane, and derrick. The details of the method used in this study are presented below [31].

The wind force calculations are based on a steady-state one-minute mean wind velocity measured at an elevation of 10 meters above the water surface. For wind velocities at a different elevation, adjustments to the equivalent 10-meter velocity can be made with the following formula:

$$U_w = u_w \left(\frac{10}{h}\right)^{1/7} \quad (32)$$

where

u_w : wind velocity at elevation, h

h : elevation above water surface

Since the wind speed is subject to gusts the one-minute mean value is converted to the hourly mean value by multiplying by 1.15. The wind forces and moment can be estimated by using the following standard formulations:

$$X_W = \frac{\rho_a}{2} U_{Wr}^2 A_T C_{Wx}(\alpha_{Wr})$$

$$Y_W = \frac{\rho_a}{2} U_{Wr}^2 A_L C_{Wy}(\alpha_{Wr}) \quad (33)$$

$$N_W = \frac{\rho_a}{2} U_{Wr}^2 A_L L_{BP} C_{Wn}(\alpha_{Wr})$$

where

X_W, Y_W : wind force in surge and sway

N_W : wind moment

C_{Wx}, C_{Wy}, C_{Wn} : wind coefficients for given wind directions

ρ_a : density of air (1.23 kg/m^3)

α_{Wr} : relative wind direction

A_T, A_L : transverse and longitudinal wind area

L_{BP} : length between perpendiculars

U_{Wr} is the instantaneous wind velocity including the ship's speed over the ground with the following longitudinal and transverse components:

$$U_{Wr} = \sqrt{U_{Wx}^2 + U_{Wy}^2}$$

$$U_{Wx} = U_W \cos \alpha_W - u \quad (34)$$

$$U_{Wy} = U_W \sin \alpha_W - v$$

where

U_W : wind velocity

α_W : wind direction with respect to Earth-fixed coordinate system

u, v : velocity components of ship in x and y directions

Then, the relative wind direction (α_{Wr}), i.e. the angle between the speed through the water and the ships heading can be expressed as follows:

$$\alpha_{Wr} = \arctan\left(U_{Wy} / U_{Wx}\right) - \psi \quad (35)$$

where ψ is the heading of the vessel. The wind coefficients (C_{Wx}, C_{Wy}, C_{Wn}) for given wind directions can be obtained by model tests or Computational Fluid Dynamics analysis. Alternatively, for early design studies, empirical coefficients based on regression analysis of model test data can be used.

2.4.3. Wave Forces

The waves affect a maneuvering ship in two ways;

- First-order oscillatory forces centered on the dominant wave encounter frequency,
- Second-order drift forces which consist of a steady component and a low-frequency component.

The first-order harmonic wave forces are much larger in magnitude compared with the second-order forces. However, the effect on the trajectory of a maneuvering vessel in a restricted waterway with limited wave heights may be ignored. Since the second-order low-frequency wave forces are also oscillatory with a mean about zero they may also be ignored. Therefore, only the second-order mean wave drift forces need to be taken into account in the maneuvering simulation procedure.

The second-order mean wave drift forces can be estimated from model tests but require a complicated measurement system design. Ankudinov and Jakobsen [32] derived the following empirical formulae by using a large number of model tests, for estimating mean wave drift force components and the wave drift moment:

$$X_{WD} = \left[0.0388\, \rho g B\, C_B\, H_{1/3}^2 \sin^2\left(\frac{T}{2\, H_{1/3}}\right)\right] \cos\beta$$

$$Y_{WD} = \left[0.0388\, \rho g\, L_{WL}\, H_{1/3}^2 \sin^2\left(\frac{T}{2\, H_{1/3}}\right)\right] \sin\beta \quad (36)$$

$$N_{WD} = \left[-0.125\, \rho g\, L_{WL}\, T H_{1/3}^2 \sin^2\left(\frac{T}{2\, H_{1/3}}\right)\right] \cos\beta \sin\beta - 0.03\, Y_{WD}\, L_{WL}$$

where

X_{WD}, Y_{WD} : wave drag force in surge and sway

N_{WD} : wave drag moment

L_{WL} : length of waterline

B : breadth of waterline

T : ship draught

C_B : ship block coefficient

$H_{1/3}$: significant wave height
β : wave direction
g : gravitational acceleration

3. Validation of the Maneuvering Prediction Procedure

To validate the mathematical maneuvering model presented in Section 2, turning and zig-zag maneuver tests were carried out for KVLCC2. The main particulars of the vessel are presented in Table 1.

Table 1. *Main particulars of KVLCC2 tanker*

Parameter	Symbol (units)	Value
Length between perpendiculars	L_{BP} (m)	320.0
Length of waterline	L_{WL} (m)	325.5
Beam	B (m)	58.0
Depth	D (m)	30.0
Draught	T (m)	20.8
Block coefficient	C_B (-)	0.8098
Midship section coefficient	C_M (-)	0.998
Longitudinal centre of buoyancy	LCB (%)	3.48 of L_{WL} (fwd)
Displacement volume	∇ (m3)	312622
No of propellers	NP (-)	1
No of blades	Z (-)	4
Propeller diameter	D_p (m)	9.86
Pitch ratio at 0.7R	P/D (-)	0.721
No of rudders	NR (-)	1
Movable rudder area	A_R (m2)	136.7
Rudder deflection rate	δ_r (deg/s)	2.34

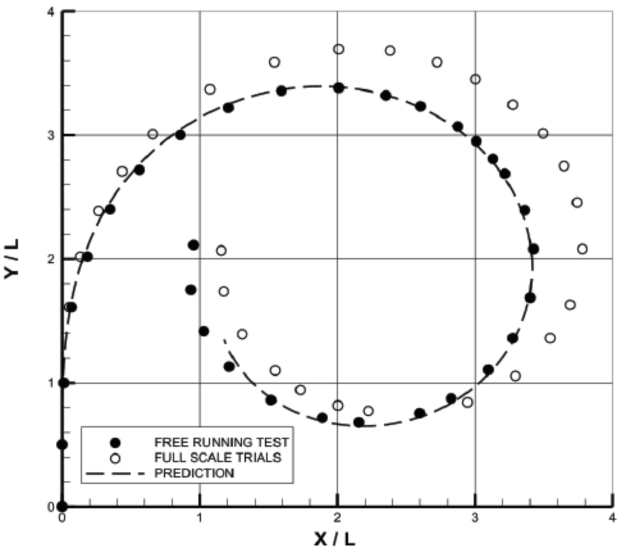

Figure 2. *Comparison of turning maneuvers for KVLCC2*

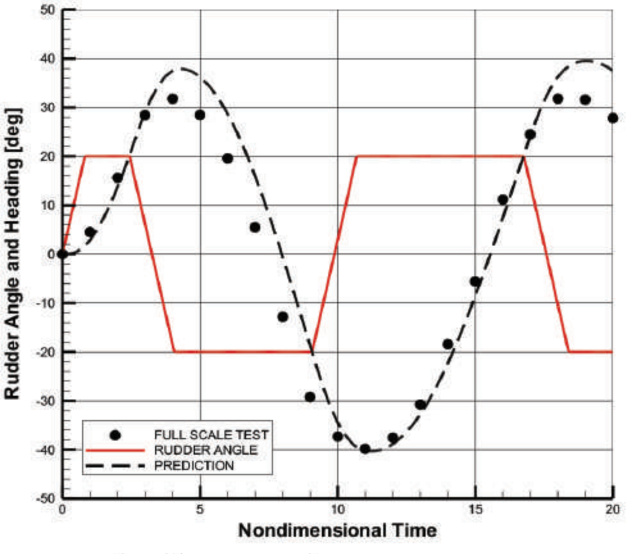

Figure 3. *Comparison of zig-zag maneuvers for KVLCC2*

A comparison of the turning circle maneuver for a rudder deflection angle, δ, of 35 degrees is shown in Figure 2. The turning simulation results are in excellent agreement with the free running test results. A similar comparison for the zig-zag maneuvering test is presented in Figure 3. It is clearly seen from these figures that the simulation results are in good agreement with the full-scale trial results. The trajectories of the vessel are plotted in MATLAB software.

4. Formulation of the Optimization Problem

This section presents a numerical optimization procedure to determine the rudder control commands required for a safe passage through the lanes of the TSS established at the Straits of Istanbul. The Strait of Istanbul lies between the Black Sea to the north, and the sea of Marmara to the south which is connected to the Mediterranean via the strait of Çanakkale. The length of the Strait of Istanbul is approximately 16.74 nautical miles, with an average width of 0.81 nautical miles. A major navigational difficulty in the Strait of Istanbul is the existence several sharp turns which require vessels to change course at least twelve times. At the narrowest point, Kandilli (700 m), a 45° course alteration is required.

In the present routing optimization approach, the theory is recast in terms of the performance criteria and the output of the process are the values of the ship maneuvering control parameters, i.e. the propeller revolutions and the rudder angle. In order to simplify the problem, the propeller revolutions are assumed to be fixed at a value corresponding to a ship speed of 10 knots which is the maximum allowed speed by the administration [11]. The objective is to minimize the total deviation from the centerline of the traffic lane.

In general, a mathematical optimization problem can be described as follows:

Minimize $f(x)$

Subject to $g_i(x) \geq 0 \quad i = 1,2,\ldots,m$

where $x = (x_1, x_2, \ldots, x_n)^T$ is the vector of optimisation variables. Thus the aim is to find the value of x that yields the best value of the objective function, $f(x)$, within a design space defined by the constraints, $g_i(x)$.

In the present routing optimization approach, the design variables x should be related to the rudder angle. It is assumed that the maximum rudder deflection angle is ±35° and the rudder can be deflected at intervals of 5 degrees, yielding a total of 15 optimization variables. In order to calculate the objective function, $f(x)$, the absolute value of the distance between the ship's center of gravity and the centerline of the traffic lane at each time step is computed and summed for the total simulation time to obtain a measure of merit representing the total deviation from the intended route. The vessel's position is determined by the coordinates of its center of gravity and the yaw angle which are calculated at each time step for the selected range of rudder angles. Then the total number of alternative trajectories is:

$$N_T = (n_R)^{n_T} \qquad (37)$$

where, n_T is the number of time steps and n_R is the number of rudder angles. For a simulation of 6 minutes with a time step of 30 seconds and 15 rudder angles, the number of alternative trajectories would be about $N_T = (15)^{12} \cong 1.3 \times 10^{14}$. The evaluation of that many alternative trajectories requires an efficient optimization procedure. The non-linear direct search method of Hooke and Jeeves [33] has been found to work well for the problem under discussion.

In order to demonstrate the effectiveness of the developed numerical optimization procedure, several scenarios were investigated. To limit the simulation time only the most critical part of the Strait of Istanbul is considered. Only the loaded condition is taken into consideration because of the greater environmental risks. A matrix of simulation cases was defined in Table 2 so that the influence of different factors which affect the safety of navigation can be investigated independently.

As a first application the northbound VLCC in ideal environmental conditions case is considered. Note that, the northbound passage is defined as "N" and the southbound passage with "S" in Table 2. As shown in Figure 4a, the trajectory of the vessel is barely within the traffic lane while the swept track violates the boundaries. It should be reminded that this trajectory represent the best option among $N_T = (15)^{18} \cong 1.478 \times 10^{15}$ alternative trajectories, where 15 represents the number of possible rudder angles and 18 represents the simulation time of 9 minutes with a time step of 30 seconds. The time step of the simulation depends on the rudder deflection rate of the vessel. For the current VLCC the rudder deflection rate is 2.34 deg/s resulting in a 30 seconds time step to be able to change the rudder angle from -35° to +35°. The rudder deflection rate and the range of rudder angle may significantly affect the maneuvering performance of the vessel. For example, as shown in Figure 4b, when the range of rudder angle is limited to -20° to +20°, the vessel cannot remain within the traffic lane even in ideal environmental conditions.

In moderate environmental conditions represented by 3 knots current, 20 knots wind and 1-meter significant wave height, the best possible trajectory for the northbound VLCC in south-westerly winds for a maximum rudder angle of -35° to +35° is shown in Figure 5a. The drift forces due to the south-westerly winds, waves and current result in significant deviation from the centerline of the traffic lane and there is a strong possibility of a collision with a

Table 2. *Simulation matrix of KVLCC2 tanker at the Strait of Istanbul*

Passage	Velocity (knot)	Environmental condition	Wind (South West) (knot)	Current (South) (knot)	Wave height (South West) (m)	Rudder angle (°)	Increment (°)
N	10	Ideal	0	0	0	±35	5
N	10	Ideal	0	0	0	±20	5
N	10	Moderate	20	3	1	±35	5
N	10	Extreme	40	5	2	±35	5
S	10	Ideal	0	0	0	±35	5
S	10	Moderate	20	3	1	±35	5

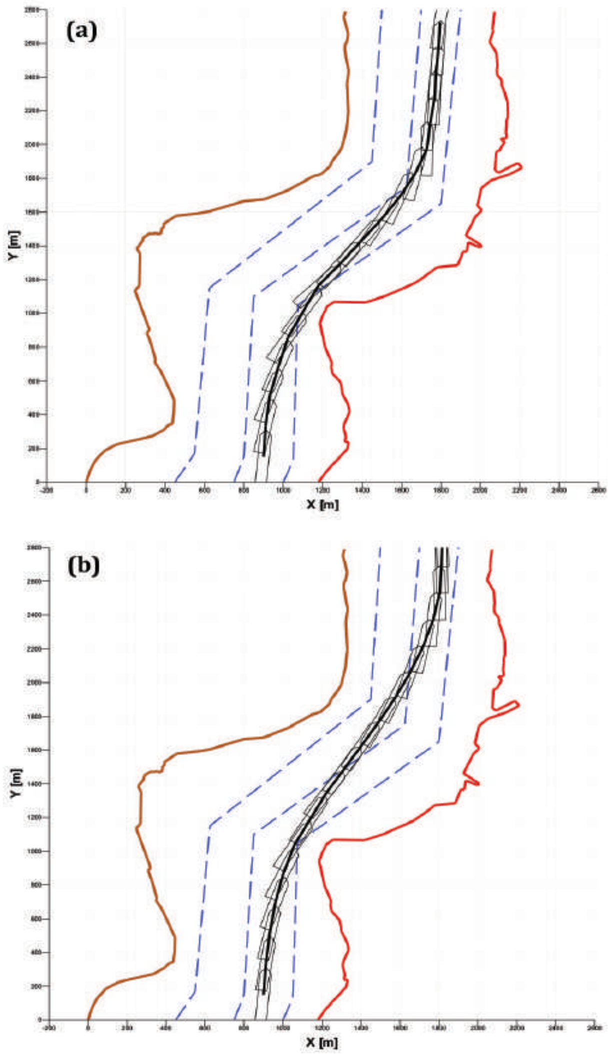

Figure 4. *Northbound VLCC, Ideal condition: (a) Maximum rudder angle: ±35°, (b) Maximum rudder angle: ±20°*

southbound vessel. In extreme environmental conditions, as shown in Figure 5b, the VLCC, even with the best possible rudder commands, could not remain within the boundaries of the traffic lane and a collision with a southbound vessel is inevitable. The best possible trajectories in ideal and moderate environmental conditions for the southbound VLCC are shown in Figure 6a and Figure 6b. Similar to the northbound VLCC, even in ideal environmental conditions, the southbound VLCC could barely navigate within the boundaries of the traffic line. In moderate environmental conditions, even with the best possible rudder commands, the vessel violates the traffic separation line resulting in a strong possibility of a collision with a northbound vessel.

5. Concluding Remarks

The main objective of the routing procedure is to determine the size of a vessel navigate within specified traffic lanes so that the possibility of a grounding or collision is minimized. An optimized ship routing procedure based on ship maneuvering simulations and non-linear direct search techniques has been developed and used to determine the best attainable route for large tankers in a restricted waterway, represented by the Strait of Istanbul, under the effects of specified environmental conditions. As a practical application, a typical VLCC was selected and the best attainable trajectories in the most critical part of the Strait of Istanbul were investigated. The major findings of these investigations are summarized as follows:

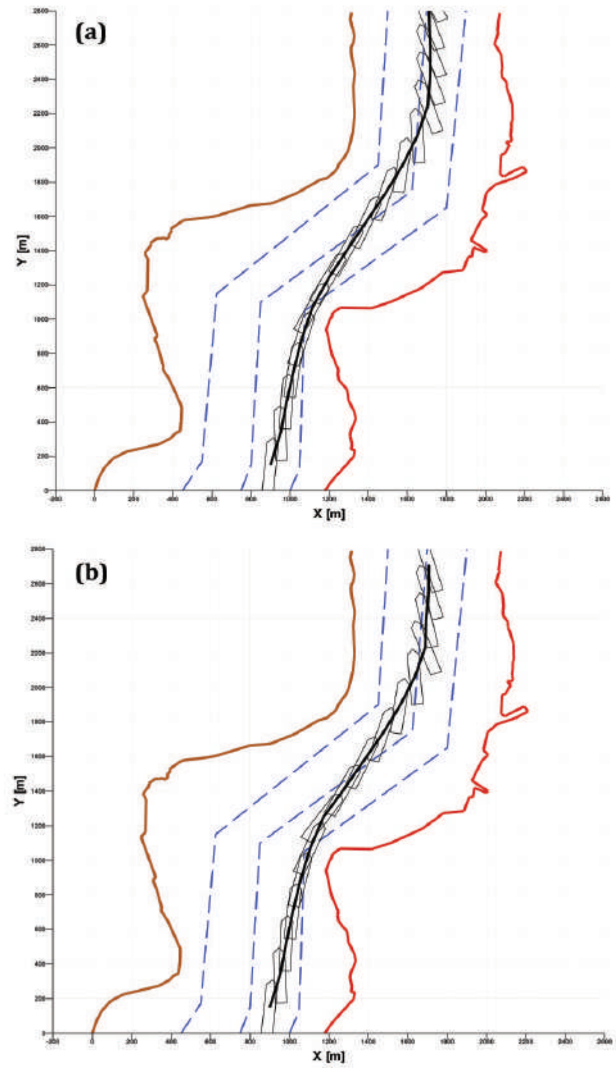

Figure 5. *Northbound VLCC, Maximum rudder angle: ±35°: (a) Moderate condition, (b) Extreme condition*

- Even under ideal conditions (no wind, no current, no wave) it is almost impossible for a typical VLCC to maintain its position within the traffic lanes in the critical part of the Strait of Istanbul. In order to prevent a collision or grounding, these type of vessels should not be allowed to be in the straits at the same time in the opposite directions

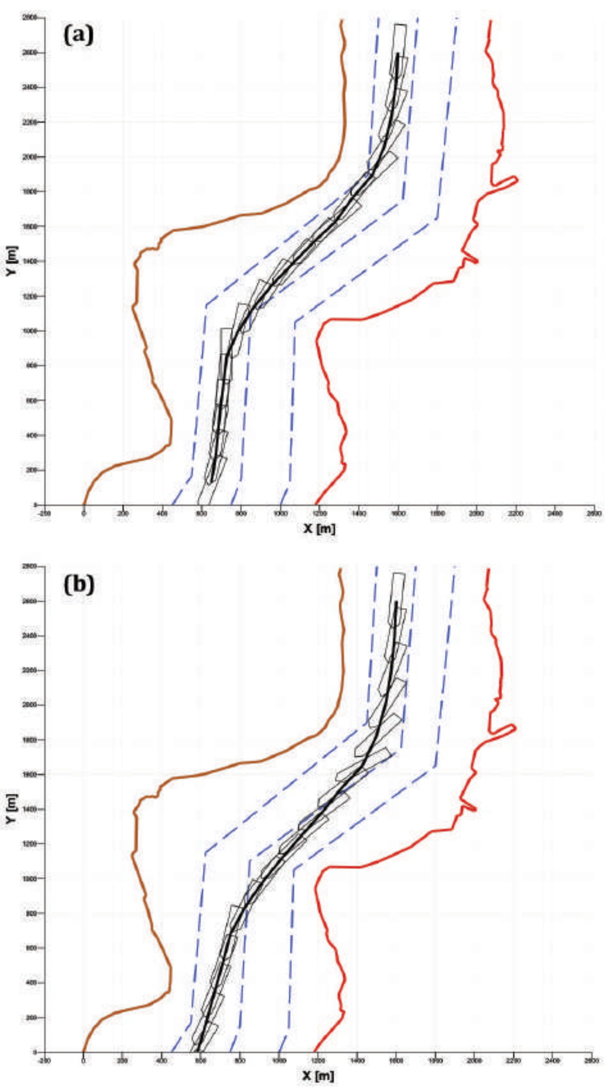

Figure 6. *Southbound VLCC, Maximum rudder angle: ±35°: (a) Ideal condition, (b) Moderate condition*

even under ideal environmental conditions.

• In moderate environmental conditions it is impossible for a typical VLCC to navigate through the critical part of the Strait of Istanbul without violating the traffic separation lanes. In such conditions only one-way traffic should be allowed to prevent collisions or grounding.

• In extreme environmental conditions, under strong winds and currents maintaining position within the lanes is not possible for typical VLCCs and they should not be allowed in the Strait of Istanbul until the environmental conditions are reduced to moderate levels.

Real time simulation of the maneuvering behavior of a vessel under the influence of wind, current and waves is such a complex mathematical problem that some simplifications are inevitable. In present study, the wind, current and wave effects are taken into account in a quasi-static manner. A fully-dynamic maneuvering simulation is a desired long-term research goal that needs sophisticated mathematical theories as well as extremely powerful computers. However, this tool could be further used to determine the ship particulars which can safely pass through a restricted waterway for specified or the maximum allowable environmental conditions.

Authorship Contributions

Concept design: K. Sarıöz, Data Collection or Processing: K. Sarıöz, Analysis or Interpretation: K. Sarıöz, Literature Review D. Öztürk, K. Sarıöz, Writing, Reviewing and Editing: D. Öztürk, K. Sarıöz.

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Exploring Instagram-Based Social Media Marketing Approaches of Yacht Training Services: A Content Analysis of Photographs

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Abstract

Instagram posts of sail training centers were examined and a comprehensive content analysis of photographs was used to comprehend the patterns of social media marketing and services offered. Two coders analyzed the Instagram profiles of five Turkish and five international yacht/sail training centers generating five main codes for a total of 288 codes with the Cohens cappa intercoder reliability calculated as 86%, which is considered reliable. The photographs were coded and analyzed using MAXQDA qualitative research software, and variables such as point of view, mood, and boat parts were explored. Qualitative analyses such as code distances mapping, code-subcodes analysis, and two-cases models comparative analyses were conducted, and results were discussed. The patterns that emerged were race focused, learning focused, license training, natural scenery/touristic appeal, warm, friendly/social, and lackadaisical/low social media activity. Several qualitative analyses were carried out, and the results were presented in terms of their contribution to the literature and managerial applications.

Keywords: Services marketing, Marine tourism, Social media marketing, Yacht training, Content analysis

1. Introduction

There is fierce competition among services across the world. Value-conscious customers with limited time seek the best option from thousands of offers, which necessitates appealing approaches. Social media facilitates efficient marketing communication by allowing customer participation [1] and the sense of belonging to a virtual community [2]. Furthermore, customer empowerment through resource integration increases value co-creation opportunities and repurchase intention [3]; additionally, image-based applications in social media enhance its benefits by expressing many words to the target customers in a short period of time [4]. According to a recent report conducted by *We Are Social and Hootsuite* [5], there are currently 4.20 billion people using social media. Over the previous year, this number has increased by 13% reaching 490 million. Approximately 45% of the world's internet users now turn to social networks for information on products and services they are considering to purchase. Nevertheless, despite the importance of the competitiveness and sustainability of social media in the market, strategies for marketing purposes remain scarce [6]. Massive amounts of social media data in various forms may now be easily extracted and used as a result of improvements in information technology [7]. Thus, companies should resort to analysis based approaches using social media data to monitor how the content or form of their message affects consumer experience and continuously implement innovations in their social media platforms for ensuring that the marketing goals of the company are met [8].

Learning to sail a yacht and becoming part of a sailing team has intrinsic attractiveness. However, yachting is an experience-based activity [9] that cannot be easily envisaged beforehand and requires enhancing elements to be motivated. Today, sailing schools and yacht training centers extensively use the visual attraction of sailors, sails, and yachts via social media. Among the applications, Instagram is the most popular social media platform for

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sail training providers to promote their operations. On the other hand, these practices are limited to a few schools and are managed intuitively rather than in a systematic manner. Thus, an in-depth study of Instagram as a marketing tool is required for a better comprehension of the social media platform and the success of marketing campaigns [10].

The aim of the study was to explore the promotion of Instagram-based social media usage patterns of yacht training centers and the use of content analysis on photos shared on social media as a qualitative research tool. Therefore, the research question is what prominent elements are used for promoting yacht training centers. Furthermore, the study aims to enhance the findings questioning variables such as geography, culture, number of posts and followers, company experience in terms of social media usage commonalities, and differences in the patterns. The research agenda will begin with a review of the literature on social media marketing and the role of visual experience in sailing, followed by an analysis of cases taken from the Instagram accounts of ten yacht training centers (Annex 1). In the Conclusion section, suggestions are made to yacht training service managers on how to effectively communicate with their current and potential customers.

2. Conceptual Background

2.1. Social Media Marketing

Social media marketing uses online networks to build relationships and share information between businesses and their customers [6]. Companies contact and engage consumers at different points in the purchasing cycle thereby making it a significant resource for marketers [1]. Social media marketing has many applications such as customer blogs, online communities (e.g., Facebook, Instagram), and media sharing platforms (e.g., YouTube). It has a rapidly growing impulse for both the decision-making processes of customers and the marketing activities of suppliers for promotion, communication, distribution, and customer relationship management [11,12]. Today, social media marketing is not just used for promoting and distributing services; it is also utilized for service development thanks to the active voice of customers and building brand loyalty [12,13] in a more cost-efficient manner [14].

There are some prerequisites to being a skillful player in social media marketing. First, the social media accounts of companies must be attractive and user-friendly to convince and engage their target customers [12]. The images used must be compatible with the service and create a proposition on customer expectations from the services [4]. Furthermore, user motivation should be positioned at the heart of the web design [6]. Chi [2] reveals that the need for online social bonding influenced customer participation attitude and inclination toward social media applications. The lifestyle, passions, and interests of customers are essentials for the desired visual social place where they think it is worth spending their time [15]. Social media users must be inspired to interact with companies for reasons related to their intellect, social standing, culture, or other factors [16]. Wibowo, et al.'s [8] study results indicate that in addition to the commercial facet, the social-oriented aspect, i.e., interaction quality between customer and company, also made an impact on the purchasing and participation intentions of the customers as well as their loyalty behavior toward social media marketing activities. The authors suggested that customer experience is influenced by a digitally created environment, which also increased the relationship quality of the company [17].

In this context, Instagram is a good instrument incorporating elements of music, story, and entertainment thereby evoking intense customer attention. Argyris, et al.'s [18] study on the effects of images in Instagram marketing revealed that images are more easily recognized, remembered, and are more effective at persuading people compared with words. Thus, it is expected that the popularity of Instagram and other photo-sharing platforms will increase daily. Djafarova and Bowes [19] and Kemp [5] state that Instagram is essential for the stimuli purchasing behavior of Generation Z customers who prefer images rather than long texts in their communications. The study conducted by Chen [10] illustrated that younger customers do not prefer advertisements that are too "obvious" and "deliberate," and thus recommended the companies to maintain up-to date marketing information while offering most recent product updates to their consumers. Based on the results of the study by Amelia and Hidayatullah's [14], Instagram has a significant and favorable impact on how people perceive the worth of luxury goods and services and contribute to consumer perceptions of luxury and purchase intention. Moreover, Instagram has been used for user-generated events; credits to user initiative and empowerment with the event management paradigm shifting as organizations are no longer the primary organizers and initiators of such events [20].

2.2. Creating a Visual Experience for Yacht Training

Undoubtedly, services need to be supported through enhancing elements to convince their target customers since "value is a function of experience" [21], and service experience cannot be predicted before being purchased [11,22,23]. Images are potent triggers for remembering and effective animators because they make the intangible tangible [24]. Providing enhanced information by placing perfectly designed physical clues of the service in the promotion activities might help alleviate some of the uncertainties [25], and using appropriate motivation factors might accelerate the tendency of customers toward services. Furthermore, Ryan [26] has stated that although participating in any sports activity needs intrinsic motivation, external stimuli are needed for long-term commitment. Thus, the imagination of the experience is a crucial part of marketing promotion activities, which requires defining the pillars of the activity during the first phase. Afterward, they are used appropriately and vigorously to entice clients to participate in any activity.

As is the case for all other services, the value acquired from sailing activity and experience cannot be predicted in advance. Sailing is a marine-based activity encompassing both tangible (i.e., boat) and intangible (i.e., crew behavior and attitude, other customers) aspects, and experience is produced based on all of their interactions. Various yachting studies have shown that human elements comprise the most influential attribute of the experience, followed by yacht attributes [27]. On the other hand, high-end yacht industry, which mostly comprises motor-yachts larger than 50 meters in length, differs from the other segments in that it has solely focused on characteristics of yachts such as swimming pools, helipads, and Jacuzzis [28]. Furthermore, participating in marine activities gives people a sense of accomplishment and competence as well as the opportunity to explore who they are [29]. Yachters have also sought for motives such as friendship development, spending time in intimate surroundings, perceiving nature and solitude, all while discovering new places [30-32].

Yacht/sail training can range from basic boat handling courses for hobbyists to international licensing education that can equip participants with a professional vocation, thus enabling them to embark on a new career path. Even though sailing is a nature/outdoor activity/sport, its training appeals to cultured, educated, white-collar city dwellers. Today, the visual appeal of sailors, sails, and boats is used extensively by sailing schools and yacht training facilities in their social media accounts, particularly Instagram. Moreover, sailing students use social media to share their personal sailing experiences. As the need for sailing training rises, so does the volume of user-generated content.

3. Research design

3.1. Research Setting

Instagram is used as the research media of the study. Instagram was launched in 2010 as a visual content-focused social networking platform, allowing users to capture photos and videos, employ embedded filters to improve images, and quickly share content with a group of friends or a larger audience of all Instagram users. According to a recent report [5], Instagram is ranked fifth among the world's most popular social media networks. Even though it is utilized for a variety of commercial promotions ranging from higher education to health by practitioners, Instagram has only been subjected to a few empirical social media marketing studies in literature [10].

3.2. Data Collection and Sample Characteristics

The present study followed an interpretive approach. Ten different social media accounts were studied, five of which belong to Turkish sail training institutes chosen to represent different approaches to their services and Instagram usage patterns with five international accounts from various parts of the world. The 'characteristics for the sample group of the study are presented in Table 1. The first ten relevant posts that were uploaded on the Instagram accounts of sail/yacht instruction centers were evaluated and analyzed. The thumbnail image serves as a still image for video posts.

Non-sail-related images, such as tributes for national holidays or anniversary celebrations were excluded. Photos

Table 1. *Sample characteristics*

	Nationality	Account owner	Significance	Posts/ Followers
1	Turkish	One Yacht Club	The only center that uses paid Instagram advertisements	400/15.7k
2	Turkish	Urla Sailing	One of the oldest trainers but with very few Instagram activity	57/570
3	Turkish	Gökova Sailing Academy	Conducts ocean going/long distance sails	189/4862
4	Turkish	Smart Sailing	Highlights happy mood, good social relations, relaxed atmosphere	286/3125
5	Turkish	Limon Sailing	Serious, race focused, advanced sailing training and teamwork courses	840/2914
6	Spain	Marbella Sailing School	Costa Del Sol - RYA licensing courses	381/4087
7	Czech Republic	The Big Bull Sailing	Trains at Croatian coasts.	229/250
8	USA	PYT	Professional Yacht Master Training - approaches sailing as a job	278/2081
9	Italy	Just Sailing	Highlights the historical and natural scenes of the Italian coast	102/195
10	Sweden	59 North	Sails at North latitudes, ice sailing, long distance sailing	2142/23.9k

posted by sail training centers with various characteristics such as training session, trainees' moods, and photos displaying boat parts were preferred in order to boost the research validity. The sample interpretation was finalized when no additional suggestions were received for improving the research [33].

3.3. Data Analysis

The first 20 Cleo covers between 1972-1974 were analyzed by researchers. They asked the participants to examine the covers and describe what they noticed. Image content analysis was pioneered in this study. Analysis started to shift toward computer software with advancements in computer technology and qualitative research software. *MAXQDA*, *NVivo*, and *Atlas* are among the most frequently used content analysis software in later research.

A comprehensive content analysis procedure was followed based on images, and two coders were employed with MAXQDA Analytics Pro 2022 used for analyzing the images. The photos can be assessed as a whole, from the perspective of the coders, subjectively, or elements on the image can be counted/evaluated objectively. In this study, researchers have employed both strategies to analyze the media.

To increase intra-coder reliability, the first researcher examined the photos many times, as recommended [34]. The researcher employed an iterative technique, revisiting previously identified topics, fusing or separating them, and stopping when consistent results were found. Afterwards, the coding technique was divided into two phases [35]. The coding table, the hierarchical relationship of the codes, and the keywords associated to the codes were determined by the first coder, which were suggested to the second coder. During this stage, referred to as open coding, seven primary codes and twenty-one subcodes were obtained. Subsequently, the first author coded all the images and reviewed the findings with the second author. Following this preliminary stage, two sub and two main codes were canceled, and several codes were modified, with the axial coding process resulting in five main and 19 sub-codes, and the code table attaining its final shape. The first author used the final code table to code 100 Instagram posts from ten separate accounts making up a total of 288 codes. The second author evaluated the codes of the first author using a nominal scale of *agreeing* or *disagreeing* and compiled her proposals for the codes with which she disagreed. Following the final debate, three codes that could not be agreed upon among the coders were eliminated from the study.

With this procedure, the inter-coder reliability was assessed using the Cohen Kappa approach, and the kappa value was determined as 86.4% as can be seen in Table 2. Since this coefficient is above the level accepted in the literature [36], the research results are considered as *reliable.*

***Table 2.** Cohen Kappa reliability*

P_o	99.0%
P_c	92.3%
P_{c1}	0.2%
P_{c2}	92.2%
KAPPA*	86.4%
$*Kappa \cong \frac{Po - Pc}{1 - Pc}$	

4. Findings/Results

The gathered data was analyzed using MAXQDA Analytic Pro 2022 software (version 22.0.1), and the following findings were obtained. The codes and subcodes are presented with their frequencies of occurrence in Table 3.

Code matrix analysis indicates that no significant difference has been observed categorically between the Turkish and International groups of sail training centers, but the frequencies of the categories. The most notable difference is that the Turkish Instagram accounts post male and female individuals; while foreign accounts prefer team/group poses. Table 4 displays the codes that differ the most between the two groups.

Analysis of codes distances map (Figure 1) reveals three groups of themes diversifying from the other codes. Group **a*** consists of two codes that are *sails and masts* and *POV outside*, which is understandable given that images from a particular distance have sails and masts in their frames. Training centers use group **a*** photos to highlight the **boat** posting drone photos or photos taken from other yachts. Group **b*** has the POV inside photos, which contain male and female individuals, focused/learning and happy/relaxed moods, and steering shots which all highlight the ambiance of the inner spaces of yachts. This group aims to present the scope of their services to their target audience and social media followers.

Figure 2 displays the codes derived from the specific parts of boats. The wheel/rudder/steering (28 times) is the most frequently depicted feature of the boat, usually accompanied with a trainee steering the yacht, followed by the masts and sails (24 times). Even though the major theme is sail and yacht, photographs that do not contain any of those have been coded nine times.

Table 3. *Code Frequencies*

Mood	**41**	**Yacht /Boat**	**90**
Happy/relaxed/social	21	Wheel/Rudder/ Steering	28
Learning/Focused	13	Sails/Mast(s)	24
Fast/Adventure	7	Multiple boat/yacht	13
Point of View (POV)	**74**	**No boat/No sail**	**9**
POV Inside	41	Winches	9
POV Outside	33	Berthed/Alongside/ On land	7
People	**43**	**Other codes**	**40**
Male	15	Scenery/Nature	12
Female	14	Advertisement/Flyer	9
Group/Team/couple	14	Race related/ Ceremony/Graduation	9
Main Codes	**5**	Food & Beverage	5
Subcodes total	***288***	Night Photo	5

Table 4. *Code matrix comparison Turkish-Foreign*

Codes	International	Turkish	Difference
Male	3	14	11
POV inside	25	16	9
Team	10	4	6
Female	7	13	6
Scenery nature	8	3	5

People's moods have been coded into three categories (Figure 3): happy/relaxed/social (21 times) when the environment is more about enjoying the time spent, learning/focused (13 times) when the focus is on training, and fast/adventure (seven times) when the photo highlights speed or adventurous occurrences. Instagram profiles of training institutions that promote themselves as having good social settings frequently employ the happy/relaxing/ social mood.

To analyze the patterns of the shared posts, the photographs were categorized according to point of view (Figure 4). If the camera was inside the boat when the photo was taken, the point of view is coded as PoV inside (41 times); if the camera

Figure 1. *Codes Distances Map**

**Code distance maps depict the relationship between codes. The more two codes co-occur, i.e., the more similar they are in terms of their use in the data, the closer they are placed together on the map*

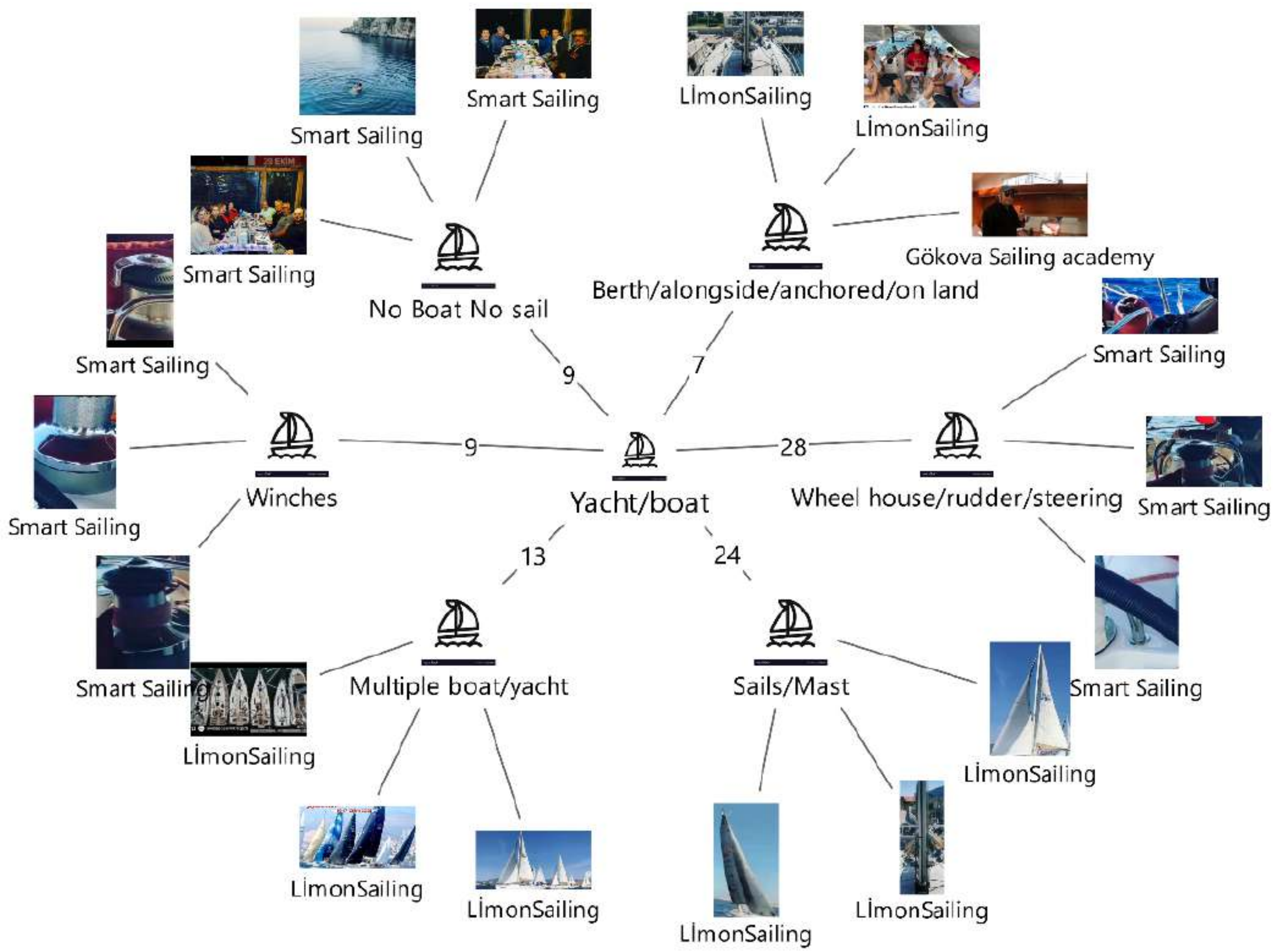

Figure 2. Codes and subcodes of Yacht/Boat

was outside the boat when the photo was taken, such as a drone shot or a snapshot taken from shore or another boat, the point of view is coded as PoV outside (33 times).

The remaining codes are classified as *other codes* (Figure 5), which include advertisements/flyers (9 times), food/beverage photos (5 times) that are mostly coded alongside a happy/relaxed mood code, night photos (5 times), race-related or ceremony of a race event or graduation event posts (9 times), and scenery photos of nature, touristic places, or artsy photos (12 times).

4.1. Two Cases Models and Comparative Analyses

Several case comparison analyses were performed while reviewing the data. Many of them did not reveal any substantial differences in the social media usage patterns of the sail training center clusters. The following are several examples of comparative case analyses that exhibit some degree of difference.

Turkish-International two cases model analysis: The main distinction is that Turkish Instagram profiles post individuals (male 14, female 13) whereas international profiles do not tend to as much (male 3, female 7). When it comes to posting persons, international profiles favor group shots (International 10, Turkish 4), which can be interpreted as a cultural difference. Highlighting scenery is used more by the International profiles (International 8, Turkish 3), such as Just Sailing from Italy presents historical tourist spots in the background, and 59 North posts ice and snow scenes to attract the visitors' interest, is an example of geographical difference as each country highlights their unique attributes on their social media accounts. Turkish profiles shared sunrise/sunset scenes on all of their three scenery codes (Figure 6).

License training-casual social two cases model analyses (Figure 7): Two of the ten profiles chosen are license training schools (Marbella and PYT), which have legislative prerequisites, while two are more casual, social sail training centers (Smart and Just), offering a friendly social setting. Some significant disparities were discovered following an analysis of the Instagram posts of these sets.

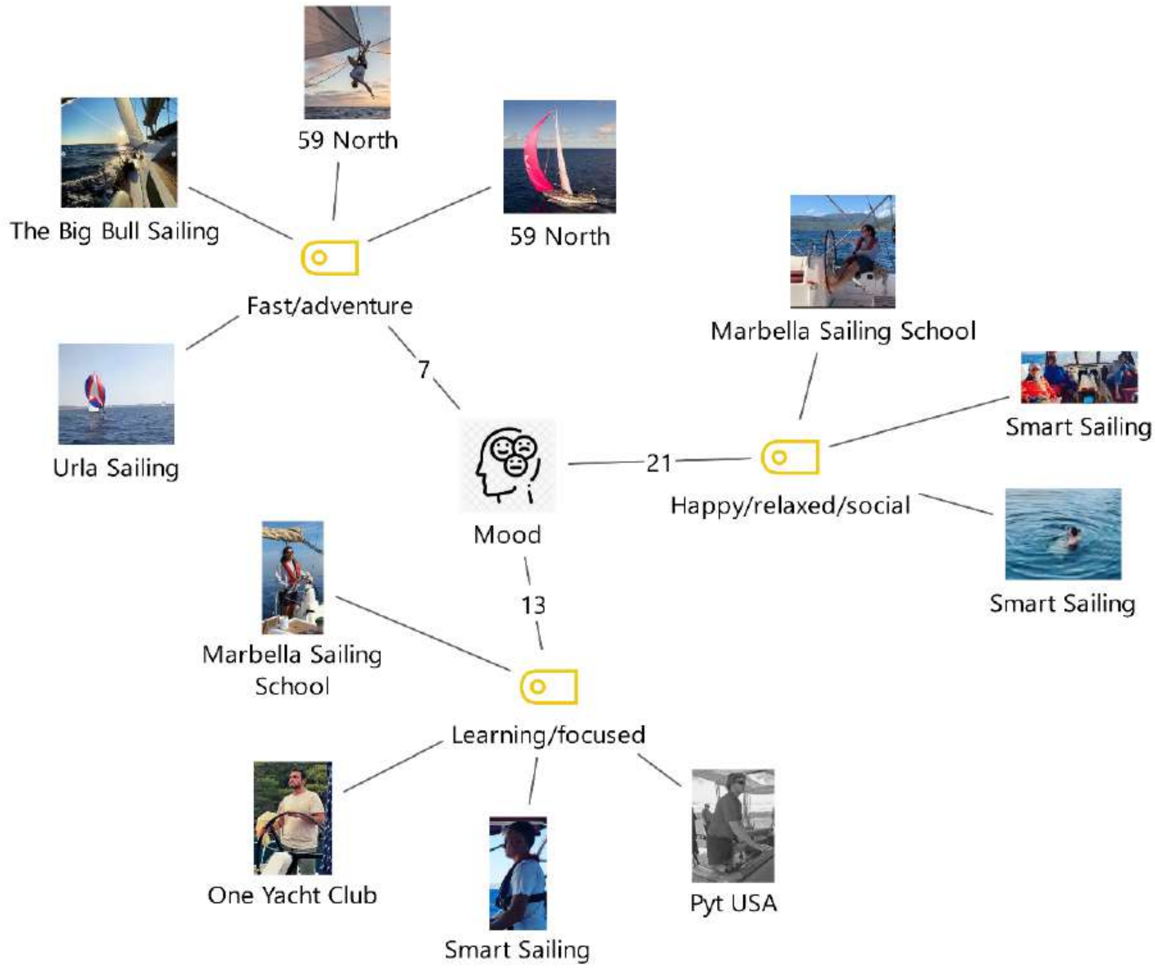

Figure 3. *Codes and subcodes of the mood*

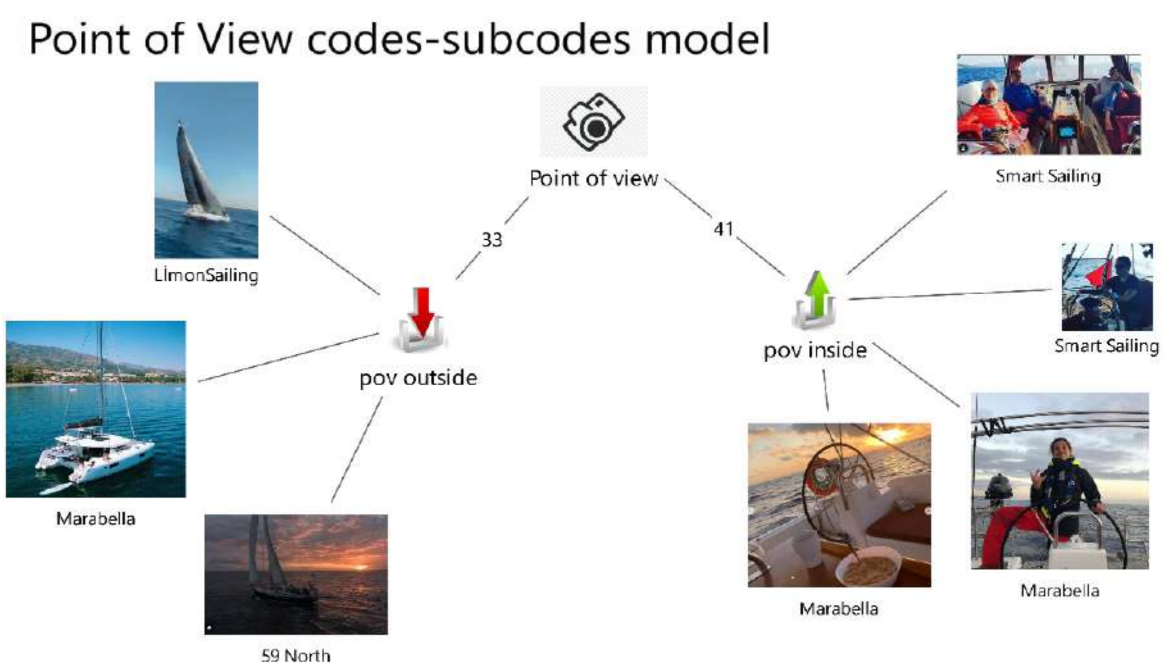

Figure 4. *Codes and Subcodes of point of view*

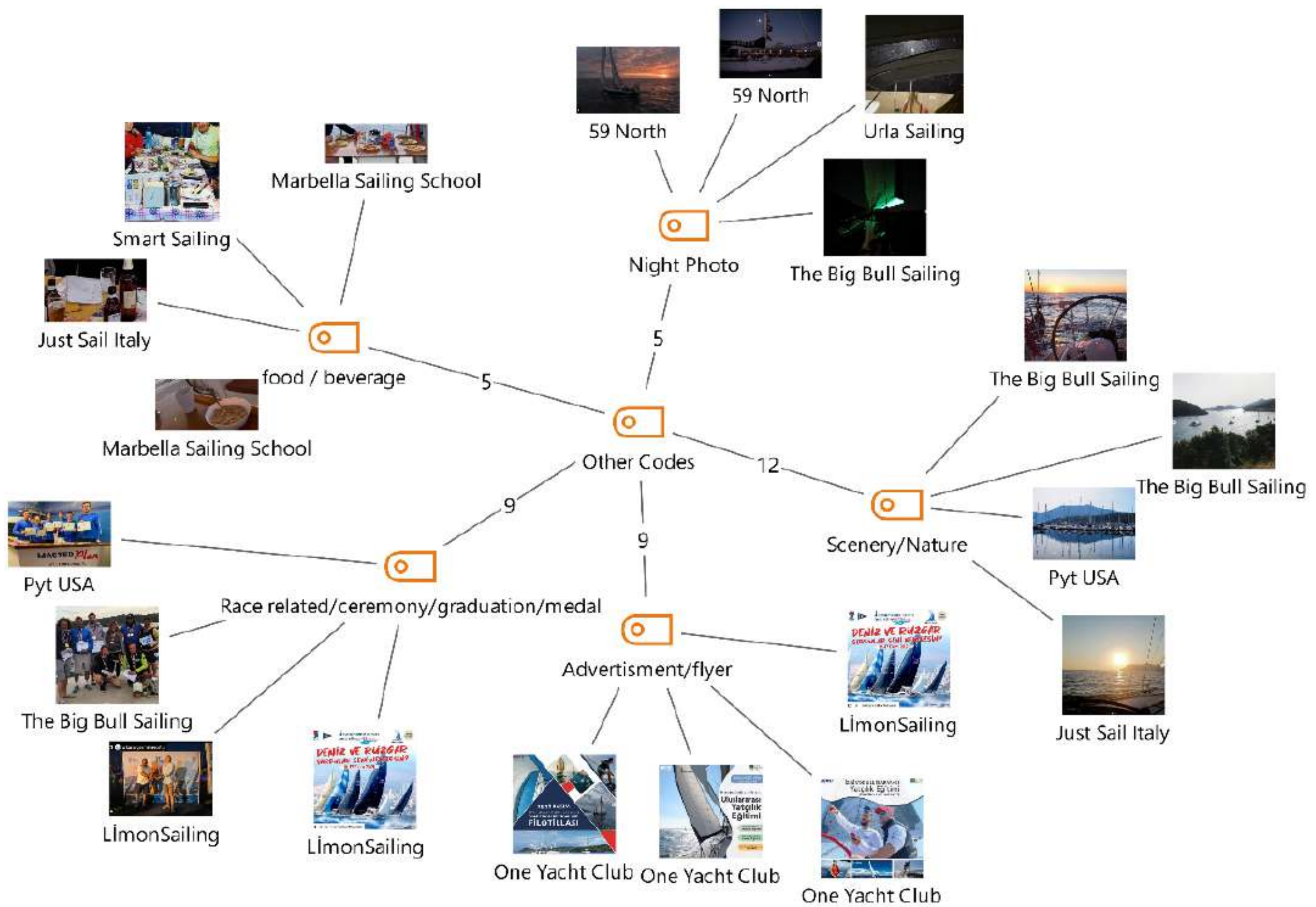

Figure 5. *Other codes*

Advertisements and flyers are exclusively posted on licensing schools; therefore, casual/social training centers publish posts from non-moving boats as well as fast adventurous photos one after the other.

Limon Sailing- Smart Sailing two cases model analyses (Figure 8): Each of the ten accounts was modeled as two independent pair cases, and a total of 45 distinct models were run and analyzed. Limon Sailing and Smart Sailing have been identified to have the most substantial difference between their Instagram accounts. Returning to the two institutes' social media accounts and reviewing previous Instagram postings, the social media usage habits were discovered to be substantially different. Limon positions itself as a focused, serious, race and team training service provider. Smart, on the other hand, communicates the impression that anyone can learn to sail and that you will feel welcome and at ease here. To convey these messages, Limon prefers PoV outside shots (Limon 6 Smart 1) to showcase the sail/training performance of the yacht; on the contrary, Smart uses PoV inside shots (Smart 6 Limon 1) to present the ambiance inside the yacht. Five codes were exclusive to Limon, such as sail and masts (5 times) and multiple boats (3 times) due to outside shots and race related posts (4 times), which is one of the main focuses of their social media account. Three codes were exclusive to Smart, which are winches (5 times), due to inside shots, happy and relaxed mood (3 times), and photos of snacks and coffee coded as food/beverage (2 times).

5. Conclusion and Discussion

As customers increasingly share their service-related experiences on their personal social media profiles, the importance of social media for service marketing continues to expand. The emphasis has shifted away from "*sharing the experience*" toward "*living the experience for the sake of sharing.*" This phenomenon encourages service providers to offer *instagrammable* services, which are visually appealing in a way that is suited for photographing and publishing on social media platforms, most notably Instagram. Even though social media has practically become an integral part of the daily routine of everyone, service providers have begun to reconsider how they use social media in the light of

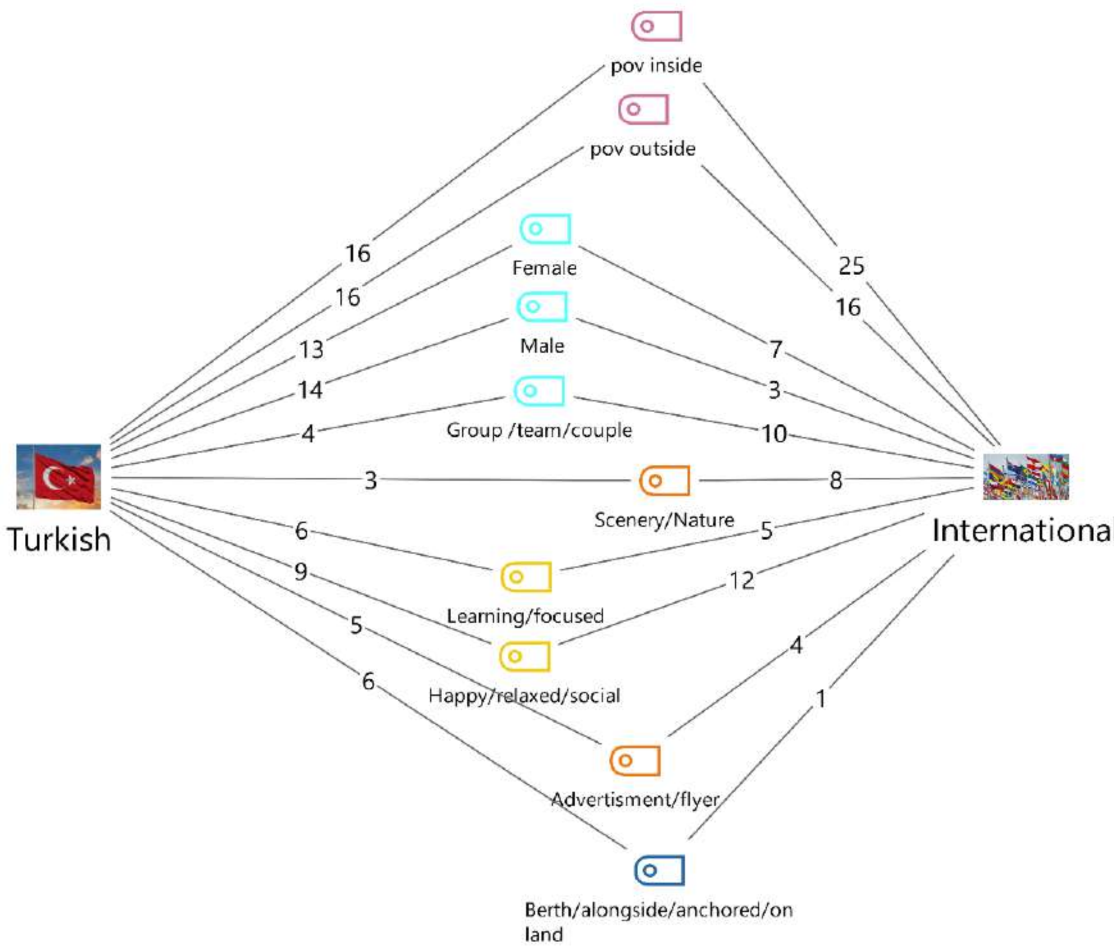

Figure 6. *Turkish - International two cases model analysis*

the prominence of the new era. In a sense, service providers supply the frames the customers may choose to share on their own social media. Thus, the present study aims to explore Instagram marketing patterns of yacht training services through photograph-based content analysis.

According to the data, the primary goal of yacht training centers is emphasized in the Instagram postings rather than the service design aspects. Some of them, for example, stress the educational part of the institutes by posting licensing elements in the images, whereas others tend to post their hedonic ambiance, such as food, coffee, and relaxed people, which prefers *POV inside* images to capture the atmosphere while sailing. Furthermore, some centers focus solely on fast race yachts, mostly via *POV outside* images, to convey the notion that they are training individuals and preparing teams for sail races. In addition, destination attributes are also visible especially in the Instagram accounts of European based institutes. As an example, historical spots in Italy or glacial fjords in Sweden are also marketed alongside to training services. It can be said that using such aspects to create a distinct vivid representation in the minds of their target clients is one of the most popular social media marketing techniques employed by training institutions. On the other hand, the service features provided are not clear with a lack of novelty regarding the services in the photos, both of which are fundamentals of social media marketing [4,12]. Furthermore, printing text messages on photos and carrying complex communications are rarely employed. According to the literature, Generation Z needs to be informed with simple messages [10], which is consistent with the findings of our study.

Even though the diversity of the patterns was not as extensive as initially predicted, several trends emerged after conducting a thorough study on the social media accounts of Turkish and international sail training institutes. The most frequently used themes are;

- Race focused,
- Learning focused,
- License training,
- Natural scenery/touristic appeal,
- Warm, friendly/social,
- Lackadaisical/low social media activity.

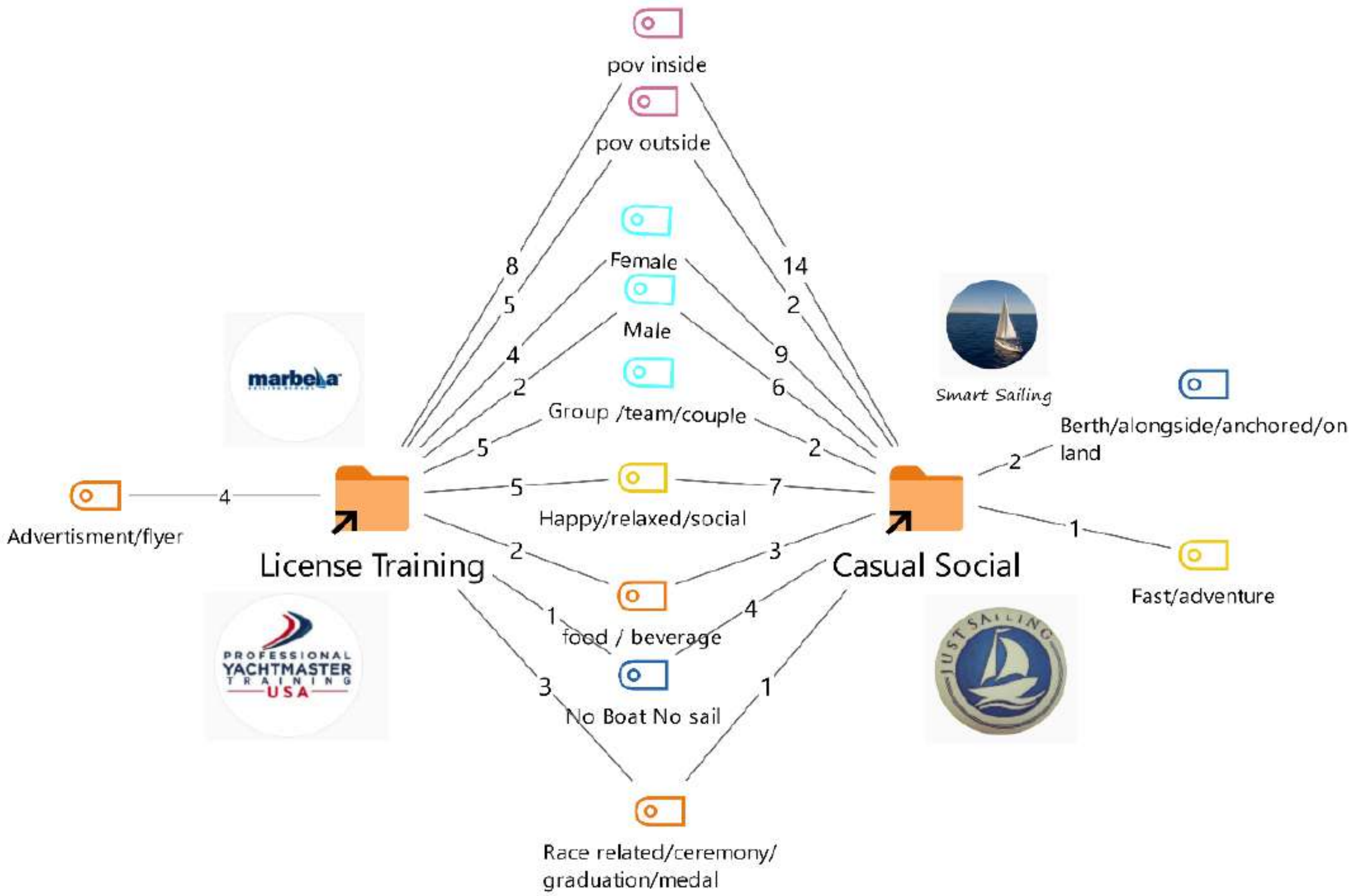

Figure 7. *License training - casual/social two cases model analysis*

The study results reveal that international institutes post more of the themes connected to the *motivations* of people who are interested in yachting [30-32] such as sensing nature, discovering new places, sharing experiences with friends, and socializing.

Moreover, the volume of training center activity and the number of trainers/trainees/boats have been found to be uncorrelated to social media engagement. Some accounts have many students but few Instagram posts/followers, while the opposite may be true for others. Furthermore, image quality ranges from smartphone snap shots attempting to capture and share the moment to high-quality images obtained by air drones or professional photographers.

The study makes some theoretical contributions to the relevant literature. The use of content analysis on photographs is limited in social media research. The present study shows that analyzing visual data produced by service providers can disclose a wealth of information about the services provided. Instagram is a rapidly developing image-based social media platform that is a strong source of visual data and has had a few studies undertaken in the field of social media marketing and this study is the only one published so far on yacht and sail training.

Some suggestions can be offered for social media marketers based on the findings. Service providers of all types should maintain the prominent features of their services accessible on their social media by employing pictures of the aspects they wish to convey to their present and potential customers. Specifically, services related to marine tourism such as nature, the marine environment should not be left unengaged, and the yacht and her equipment, as well as people and events even if organized by customers [20] could be highlighted. Social media communications, which are intended to be two-way, are typically underutilized. The reviewed yacht training accounts suggest that accounts that respond to comments obtain greater traffic from users. It is advised that the comments, inquiries, and remarks not to be left unanswered. Using hashtags and inviting customers to share their own images with specified hashtags on their accounts could be a practical way to grow the community.

The most prominent limitation of the study is that it has solely included Instagram as a social media platform. Other image-sharing social media networks, such as Facebook and

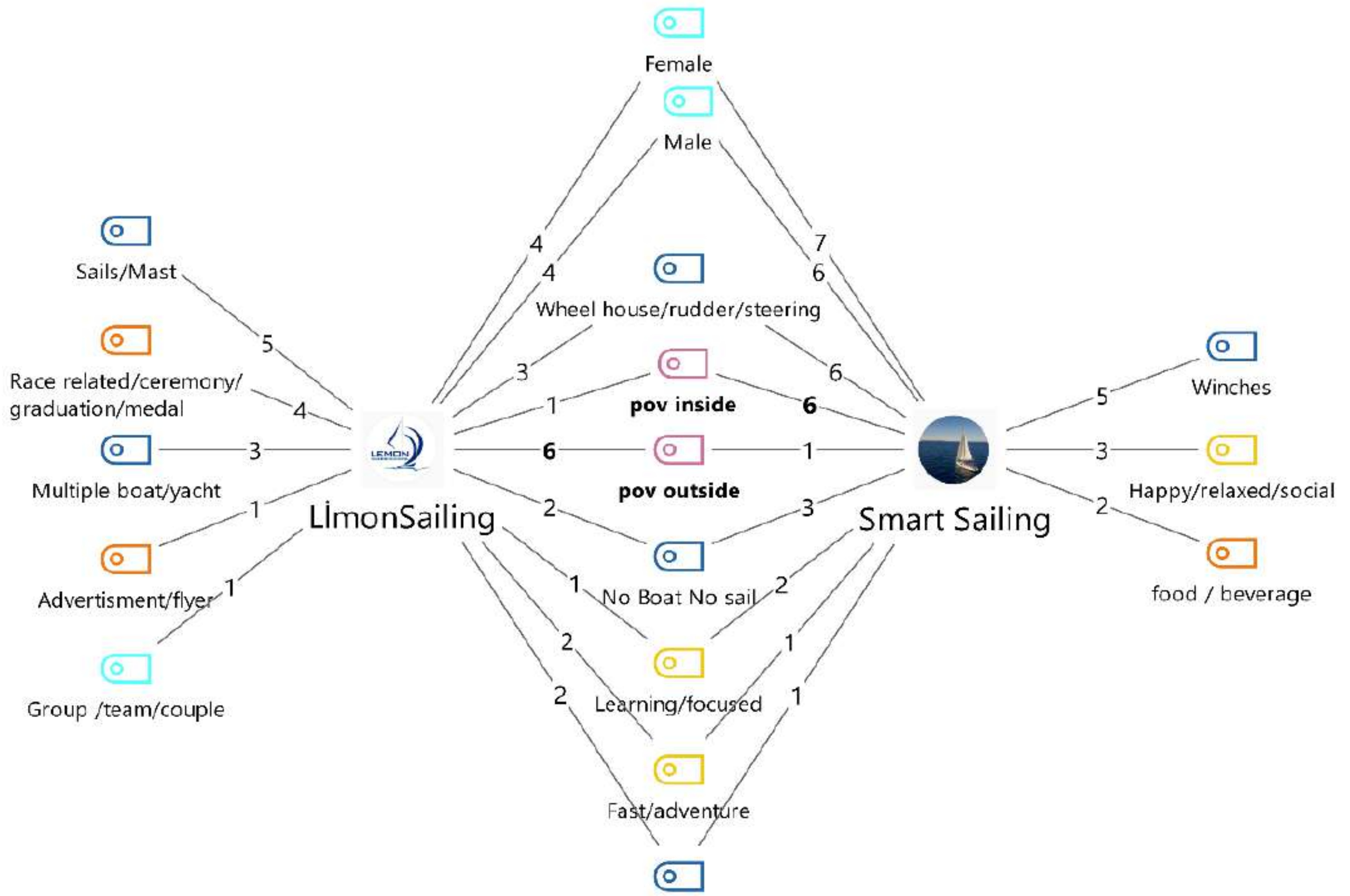

Figure 8. Limon sailing - smart sailing two cases model analysis

Pinterest, could have yielded different results. The sample of training facilities might be enlarged to include educational institutes such as maritime colleges and navy training schools, and comparative studies could be conducted to evaluate how patterns differ between them.

Image coding and content analysis on images can now provide us with additional insight thanks to recent advancements in analysis tools. Such analysis is lacking in the marine tourism industry, and additional research might be undertaken in areas such as cruise ships, marinas and terminals, superyachts, as well as water sports. Future studies can evaluate Instagram's efficiency and effectiveness in promoting education services both separately and in comparison to the results of other social media platforms, considering expected benefits, such as customer loyalty and satisfaction.

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Annex 1

List of instagram profiles subject to this study:

https://www.instagram.com/sailmarbella/

https://www.instagram.com/justsailing1/

https://www.instagram.com/lemonsailingschool/

https://www.instagram.com/thebigbullsailing/

https://www.instagram.com/59northsailing/

https://www.instagram.com/gokovasailingacademy/

https://www.instagram.com/pyt_usa/

https://www.instagram.com/urlasailing/

https://www.instagram.com/oneyachtclub/

https://www.instagram.com/smartsailingacademy/

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Understanding the Influencers of Freight Rate Forecasting Accuracy: A Meta-Regression Analysis of the Literature

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Abstract

Forecasting freight rates has been a topic of discussion for decades. Even though freight rate forecasting is regarded as a critical research topic in shipping, the literature lacks a systematic empirical account of how to obtain more reliable and accurate freight rate forecasts. This study uses meta-regression to synthesize the literature on freight rate forecasting and to test various accuracy influencers. The study confirms that the accuracy of the freight rate forecasts depends significantly on data frequency, forecasting horizon and method, market type, sample size, and the inclusion of explanatory variables.

Keywords: Meta-Analysis, Freight rate, Forecasting, Accuracy, Shipping

1. Introduction

Shipping indices, such as Baltic Dry Index (BDI), play a crucial role in making various decisions in the shipping industry [1,2]. However, it is usually arduous to accurately assess and forecast the freight markets since BDI fluctuates with a large amplitude [1,3]. For instance, BDI rose to 11793 in May 2008, fell 95% in the next six months, and reached 663 points [4]. Zhang et al. [2] explained that volatility of BDI is high because of a series of dynamic random factors; hence irregular and non-stationary features of freight rates limit the impact of forecasting models in practice. Similarly, freight rates in container and tanker markets suffer from high volatility.

Since critical decision-making is complex and vital in such an unpredictable industry, forecasting may help to facilitate decision-making. Any additional information about the future direction of the market volatility has paramount importance due to the magnitude of shipping investments [5]. This volatile nature of the shipping freight rates has attracted much attention by researchers in terms of analysing quantitatively [6] and resulted in applying complex techniques [7]. However, Duru et al. [3] highlighted the difficulties in obtaining reliable and accurate forecasts of freight rates in shipping markets. This importance of accurate freight rate forecasts has led to extensive attempts to enhance the accuracy of forecasting methods [6]. Previous researches generally indicates that no single forecasting method outperforms in all conditions [2]. Therefore, the following questions are still posed: "Is there any pattern to get more reliable and accurate freight rate forecasts" and "which influencers affect freight rate forecasting?" Although there is a consensus on the influencing factors, opinions contradict how these factors affect forecasting accuracy. This study attempts to narrow this reach gap by exploring these influencing factors' effects on freight rate forecasting accuracy. In line with this aim, this study follows a Meta-Regression methodology to provide a comprehensive and systematic review of prior freight rate forecasting studies. Most of the previous literature reviews were based on qualitative analysis and lacked quantitative proof [8]. Therefore, Meta-Regression is preferred since it provides quantitative proof.

We organized this paper as follows: Section 2 contains the proposed hypotheses based on the literature on freight rate forecasting models. Section 3 describes the materials and

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methods, including identification, coding, and methodology, while Section 4 provides detailed empirical results and an evaluation of forecasting accuracy. This study ends with a conclusion emphasizing the work's relevance of the work for practice and future research.

2. Proposed Hypotheses

Although the studies on freight forecasting have gained momentum recently, the results are objectionable since it is difficult to comprehend freight series' non-linear and non-stationary features [9]. Scholars offered various factors that could explain the surfeit of performance variability among several forecasting models such as the forecasting horizon, data availability, level of aggregation, type of product, and historical stability of data series [10]. However, it is not clear which attributes might affect the forecasting accuracy. Therefore, it is essential to examine the most suitable composite patterns for such forecasts in the industry. Therefore, we propose a series of hypotheses in this section to study characteristics of forecasting accuracy.

Traditional non-causal and causal econometric models such as ARIMA, VAR, VECM, GARCH are the most widely used models in freight rate forecasting e.g. [11-13]. On the other side, scholars suggested soft computing methods for non-linear functions in the recent two decades. Artificial neural networks (ANN) are the most explored e.g. [7,14]. Additional soft computing models such as support vector machine (SVM), wavelet neural networks (WNN) are also used. There is also a tendency to compare the proposed methods with the conventional econometric models. For instance, it is claimed that the SVM model has ascendancy in both the trend and the forecast precision [15]. Furthermore, ANN e.g. [16] and WNN models e.g. [5] also deliver notable results compared with the conventional benchmark mode. However, it is not possible to generalize that soft computing models always give better results, and it still has some deficiencies, such as parameter sensitivity and the possibility of overfitting [17]. Munim and Schramm [6] reported that simple models are better than complicated models. For instance, while Santos et al. [16] found that the performance of ANN modeling outperforms ARIMA, Munim and Schramm [18] claimed that not only ARIMA models but also VAR/VEC outperform ANN models. Geomelos and Xideas [19] reported that it is possible to reduce the forecasting errors by combining models. In this context, various hybrid models such as ANN-based combinations e.g. [20], fuzzy integrated methods e.g. [21], and ensemble forecasting models [17] have been developed. It is indicated that the proposed models are superior compared to the conventional benchmarks. On the other side, Zeng and Qu [22] forecasted BDI using econometric, soft computing, and hybrid models and found close accuracy rates. To sum up, although each proposed model offers strong evidence, claiming better accuracy than the others, accuracy varies according to the structure of the models used. Therefore, since there is no consensus on the issue, we developed the following hypothesis to reveal the effect of the forecasting method on forecasting accuracy.

H_1: The modeling method employed significantly affects the accuracy of freight rate forecasting.

Shipping markets based on the transported cargo have quite different dynamics. Although the majority of the literature consists of studies on the dry bulk shipping market e.g. [4, 23] due to market maturity and data availability, there is increasing attention on freight forecasting in the container market e.g. [6,18,24] and tanker market e.g. [16,25,26]. Zeng et al. [9] asserted that more empirical studies for freight rates of different ship types would provide contributions to confirm the reliability and applicability of the methods proposed. We extend this suggestion over the container, tanker, and dry bulk shipping markets, and given each market has unique characteristics. Hence, we put forward the following hypothesis:

H_2: Type of the market significantly affects the accuracy of freight rate forecasting.

It generally tends to form forecasting models with exogenous variables for complex dynamic processes [7,16,18,20]. However, there are findings that forecasting attempts using auxiliary information show higher accuracy e.g. [1, 7]. According to this common explanation, the positive effects are observed between explanatory variables and freight rate forecasting accuracy. However, positive effects are by no means guaranteed to increase the accuracy. Also, theoretically, exceptions might have occurred. Thus, we have an intention to determine whether explanatory variables have a positive impact on forecasting accuracy with the following hypothesis:

H_3: Explanatory variables have a positive effect on the accuracy of freight rate forecasting.

The shipping industry suffers from volatility, cyclicality, seasonality, and noise [1,27]. This structure of the shipping industry affects forecasting accuracy. Extending this rationale, Randers and Göluke [27] indicated that there is only noise in shorter time horizons and the accuracy of the forecast is lower in longer time horizons due to unpredictable events' impact on cyclicality. Although it is impossible to make point forecasts, a high likelihood of success in forecasting accuracy could be achieved. In this sense, Munim and Schramm [6] emphasized that it is necessary to forecast freight rates over different forecasting horizons to confirm the models' robustness. Some scholars found that short-term forecasts can obtain accurate forecasts [7]. For instance, Nielsen et al. [24] asserted that the developed forecasting model should be at least six weeks out of sample with a MAPE value of less than 5 percent. It is a consensus that the long-term validity of the models is weak and time-lag effects for short-term forecasting have attracted scholars e.g. [6,20]. Kasimati and Veraros [28] claimed that shorter time horizons with smaller ships improve the quality of the forecasts. However, Cullinane et al. [11] stated that extremely long-term horizons could obtain accurate forecasts due to the asset investment in the physical shipping markets. As a result, there are different and conflicting perspectives in some cases on the forecasting horizon. Given the inconsistencies in the literature, we qualify this hypothesis by asking whether the accuracy of the freight rate forecasts is affected by the forecasting horizon.

H_4: Forecasting horizon affects the accuracy of freight rate forecasting.

Sample size should be designed to describe data variation tendencies. As proposed by Nielsen et al. [24], it is crucial to balance the forecast horizon and the sample size used to fit the model for the desired accuracy. Similarly, Gharehgozli et al. [21] highlighted that utilizing the entire sample to improve the forecasting accuracy of freight rates would not be a rule of thumb. Duru et al. [3] emphasized that a shorter sample period is important for achieving or improving accuracy. To sum up, the sample size in forecasting models appears to be controversial. Therefore, we propose the following hypothesis to reveal the impact of sample size on the accuracy of the freight rate forecasts:

H_5: Sample size affects the accuracy of freight rate forecasting.

Data frequency is another factor that influences the predictive power of the models. Results suggest that different data frequencies give different results, especially depending on the models used. Zhang et al. [2] found that DFN-AI models exhibited more significance in the weekly BDI predictions than daily data forecasting. Munim and Schramm [6] found that the ARIMARCH model outperforms ARIMA models while performing short-term weekly predictions. Empirical findings suggest that data frequency influences the accuracy of the freight rates, but results also vary regarding the modeling methods used. In this context, the influence of data frequency on freight rate forecasting should be investigated in detail since the picture seems fuzzy. Furthermore, it should be clarified whether there is any influence of data frequency apart from the used modeling method. Thus, to properly understand these nuances, we proposed the following hypothesis:

H_6: Data frequency affects the accuracy of freight rate forecasting.

3. Materials and Methods

3.1. Identification, Screening, and Classification of Studies

We a systematic search strategy to identify all relevant studies. First, various databases were used to identify both peer-reviewed and grey literature. Then, as "search in" options, we select "Article Title, Abstract, Keywords," "Topic," "Title, Keywords, Abstract," "Item Title, Abstract," "Title, Abstract," and "Title, Keywords." The optimal keywords after iterative keyword screening were "freight forecast*" and "freight rate forecast*."

Timespan was set as "all years" for each inquiry, so all relevant papers up to September 17, 2020, were listed in the identification phase. Although no language was selected in the search terms, we progressed only to studies published in English. This process yielded 1878 results, of which 1242 results are from Scopus, 541 are from Web of Science, 34 are from Wiley Online Library, 27 are from Jstor, 19 are from Emerald, and 15 are from Taylor and Francis Online. Here 475 duplicates were removed and the search yielded 1403 novel references as depicted in Figure 1 based on the protocol of Moher et al. [29]. In the screening phase, we reviewed each of the remaining studies separately within the scope of research and found 1166 studies as irrelevant. Studies that are not related with shipping and forecasting were regarded as irrelevant. The remaining 237 studies were evaluated within the scope of eligibility, and it was determined that 182 of them were not related to freight rate forecasting accuracy. In addition, we could not access nine studies, and 46 studies remaining. Additionally, we added 14 studies from the references of those studies, and we reached 60 studies on freight rate forecasting accuracy. However, since various accuracy metrics were used in these studies, we selected RMSE and MAPE among those that employed different accuracy metrics. Finally, we included 24 studies that used RMSE and 17 studies that used MAPE for accuracy metrics in the meta-analysis. Details of all studies used for conducting meta-analysis are available upon request.

3.2. Coding

The influencing variables were grouped and coded based on the selection criteria mentioned above. The authors initially coded each article to improve coding accuracy. We started with a coding strategy including country, source title, aim, findings, accuracy measurement, market type, modelling method, data source, explanatory variable, forecasting horizon, and sample size. The data was then checked for coding errors. If there were disagreements about the codes,

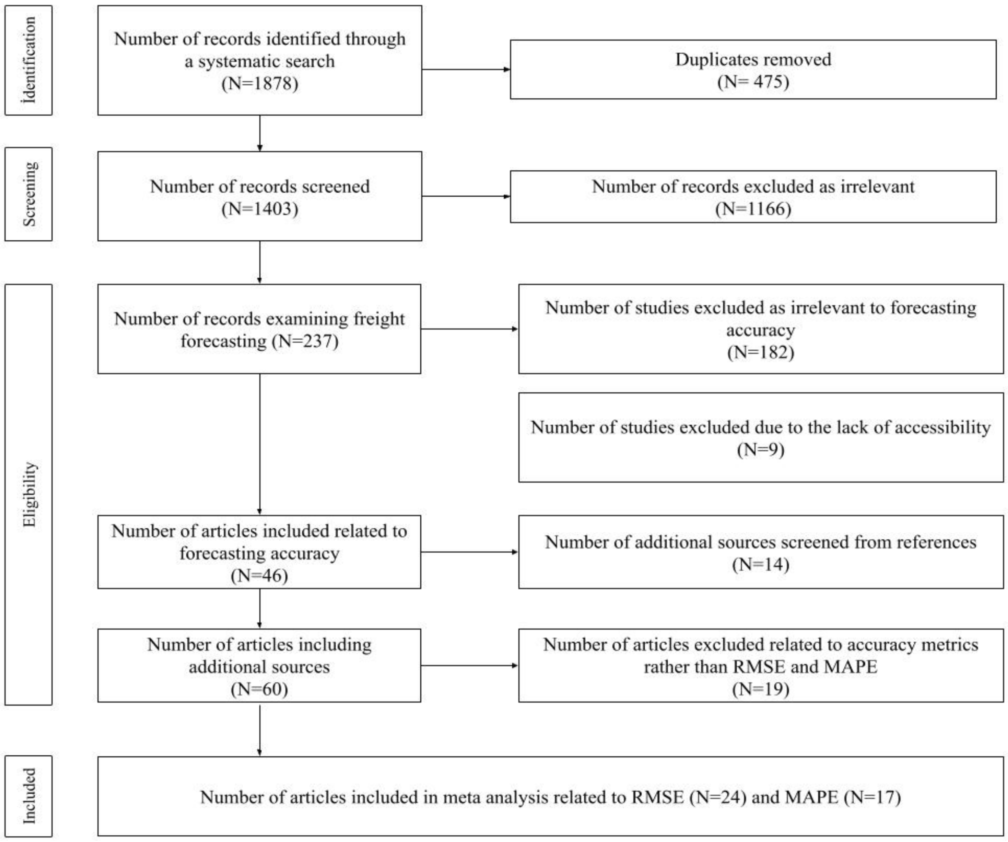

Figure 1. *A flowchart of the screening protocol and the publications that were included*

the articles were advanced screened until a consensus was reached. Table 1 provided a definition of coded data as well as basic descriptive statistics. By utilizing these variables, this study intends to evaluate the hypotheses above.

Detailed data to articles in the Meta-Regression with respective descriptive statistics for RMSE and MAPE would be provided upon request. Finally, 878 RMSE observations from 24 studies were used, as were 276 MAPE observations from 17 studies. In these studies, forecasting accuracy measures such as RMSE (40.0%), MAPE (28.4%), and Theil's U (11.6%) were most commonly used. Only MAPE and RMSE are included in the Meta-Regression due to comparability.

3.3. Meta-Regression Methodology

In this study, a Meta-Regression methodology is applied to explain the effects of different modeling variations on the accuracy of freight rate forecasting studies. The effect size used in the study is the forecasting errors collected from the papers used for meta-analysis, as in Sebri [30]. As indicated by Nelson and Kennedy [31], model-specific challenges arise as heteroscedasticity, heterogeneity, and non-independence of observations, as well as non-normality problems, while estimating Meta-Regression models. To overcome these problems and ensure the robustness of the empirical results, three estimators are employed in this study: Ordinary least squares (OLS), weighted least squares (WLS), and quantile regression (QR). First, to achieve the objective of this study, generic Meta-Regression is estimated with OLS in Equation 1 and 2:

$$\text{Log(MAPE)}_i = \beta_0 + \sum_{k=1}^{K} \beta_k X_{ki} + \varepsilon \qquad (1)$$

$$\text{Log(RMSE)}_i = \beta_0 + \sum_{k=1}^{K} \beta_k X_{ki} + \varepsilon \qquad (2)$$

where $MAPE_i$ and $RMSE_i$ are the estimates taken from the i^{th} study, β_0 reflects true effect/intercept, β_k is the coefficients of independent variables, X_k is the meta-independent variables taken from the i^{th} study, and ε is the error term. OLS estimation of Eq. 1 is biased due to heteroscedasticity as indicated by the results of the Breusch-Pagan heteroscedasticity test shown in Table 2. Then to reduce heteroscedasticity for more efficient estimation, known as the WLS, is estimated. In WLS, weights are taken as the inverse logarithm of the sample size. QR, a robust alternative to these regression methods, is also utilized in this paper due to its robustness against heteroscedasticity and normal distribution assumption. We selected five representative quantile points (10th, 25th, 50th, 75th, and 90th). There is no empirical consensus on which quantile to use and mostly, a selection of the quantile made arbitrarily [32]. The optimal quantile was selected using box plots shown in Figure 2. In some quantiles, the differences between OLS, WLS models, and QR models were small. In contrast, especially in RMSE models, there were differences to a great extent in the distributions of the fitted values. QR model in 50th quantile for both RMSE and MAPE estimates presented similar estimates to those of the OLS model. Therefore, the estimated QR model in the 50th quantile was selected as the empirical model to be referenced result.

Table 1. *Variable definition and descriptive statistics*

		Codes from MAPE estimations			Codes from RMSE estimations		
Variable	**Description**	**No**	**Mean**	**Std. Dev.**	**No**	**Mean**	**Std. Dev.**
Dependent Variable							
MAPE	The MAPE's reported value	276	1.5358	7.1940	-	-	-
RMSE	The RMSE's reported value	-	-	-	878	433.580	3060.041
Independent Variables							
Forecast Periodicity							
Daily	A dummy variable equal to 1 if the data used are of daily frequency, 0 otherwise.	103	0.3786	0.4859	132	0.1505	0.3577
Weekly	A dummy variable equal to 1 if the data used are of weekly frequency, 0 otherwise.	105	0.3860	0.4877	93	0.1060	0.3080
Monthly[a]	A dummy variable equal to 1 if the data used are of monthly frequency, 0 otherwise.	59	0.2169	0.4129	643	0.7331	0.4425
Yearly	A dummy variable equal to 1 if the data used are of annual frequency, 0 otherwise.	5	0.0183	0.1345	9	0.0102	0.1008
Forecasting Horizon							
Short-run	A dummy variable equal to 1 if the study deals with short-run forecasts, 0 otherwise.	209	0.7683	0.4226	504	0.5746	0.4946
Medium-run[a]	A dummy variable equal to 1 if the study deals with medium-run forecasts, 0 otherwise.	56	0.2058	0.4050	227	0.2588	0.4382
Long-run	A dummy variable equal to 1 if the study deals with long-run forecasts, 0 otherwise.	7	0.0257	0.1586	146	0.1664	0.3727
Forecasting Method							
Econometric	A dummy variable equal to 1 if an econometric model was employed, 0 otherwise.	73	0.2683	0.4439	689	0.7856	0.4106
Soft Computing	A dummy variable equal to 1 if a soft computing model was employed, 0 otherwise.	101	0.3713	0.4840	95	0.1083	0.3109
Hybrid[a]	A dummy variable equal to 1 if a hybrid model was employed, 0 otherwise.	98	0.3602	0.4809	93	0.1060	0.3080
Type of the Market							
Dry market	A dummy variable equal to 1 if dry market was targeted, 0 otherwise.	214	0.7867	0.4103	564	0.6431	0.4793
Tanker[a]	A dummy variable equal to 1 if tanker market was targeted, 0 otherwise.	14	0.0514	0.2213	285	0.3249	0.4686
Container	A dummy variable equal to 1 if container market was targeted, 0 otherwise.	44	0.1617	0.3689	28	0.0319	0.1759
Other Characteristics							
Sample size	The study sample size	272	776.0259	1220.532	878	401.961	576.534
Explanatory variables	A dummy variable equal to 1 if an explanatory variable was used, 0 otherwise.	32	0.1176	0.3227	345	0.3933	0.4887
[a]Indicates an omitted category in the meta-regression estimation							

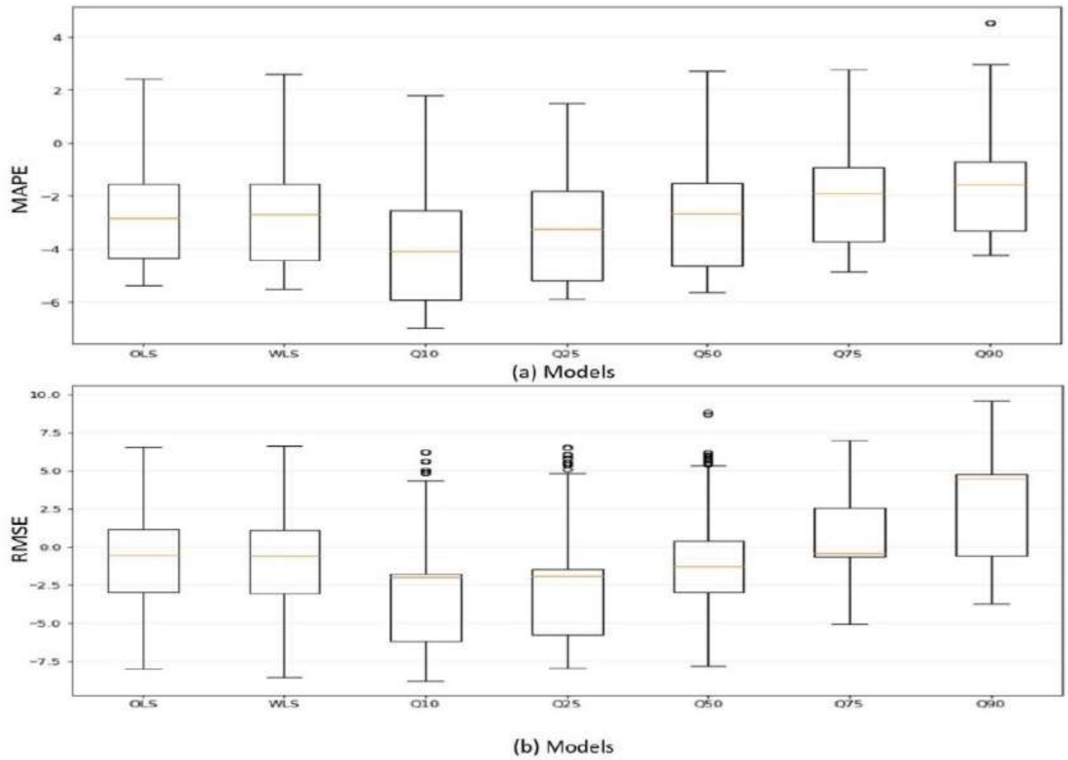

Figure 2. *Boxplot of the estimated models for MAPE (a) and RMSE (b)*

4. Results and Discussion

Table 2 summarizes the Meta-Regression and test results for the hypothesis (H1-H6). The adjusted R^2 values show that the Meta-Regression models are successful in explaining 59.6% of the variation in log (RMSE) and 69.7% in log (MAPE). The pseudo-R^2 is also used to evaluate the QR models' goodness of fit. Since the number of studies using RMSE (24 studies, 878 observations) is significantly greater than the number of studies reporting MAPE (17 studies, 276 observations), log(MAPE) Meta-Regression results should be regarded as additional analysis and a sensitivity check for log (RMSE) estimates. The regression results show that, the forecasting accuracies of the different forecasting metrics vary in some models (while soft computing methods have a significant effect on MAPE estimates, they present an insignificant effect in RMSE estimates). The reasons can be considered as the amount of studies employed for the analysis and the information loss caused by the accuracy metrics as similarly indicated by Liu et al. [10]. Extending this rationale, it is explained as RMSE is based on the scale of the data, while MAPE is based on percentage errors. Therefore, the magnitude of the effect in the RMSE models is greater than in the MAPE models, which is consistent with the supporting arguments for the differences discussed above.

As illustrated in Table 2, hypotheses H_1 is supported. Log (RMSE) estimates suggest that econometric models have a negative and highly significant coefficient, while soft computing models have insignificant coefficients; that is, econometric models tend to provide more accurate forecasts. Log (MAPE) estimates present positive and highly significant coefficients for both modeling methods. This means that the forecasting accuracies of the different models change significantly, and when the two methods were compared, econometric models outperformed the soft computing methods. The outcome of this estimation supports similar findings by Munim and Schramm [18]. For H_2, the forecasting accuracies of the different markets differ significantly. Both log (RMSE) and log (MAPE) present highly significant results (except for the container market in RMSE with OLS regression). Our expectation in this regard is consistently supported due to the relatively short history of the tanker, and container freight rate forecasting studies. However, BDI dates back to 1985, and many scholars have attempted to forecast BDI and explore enhancing the forecasting accuracy of BDI. This finding confirms Zeng et al. [9] as more empirical studies are needed for freight rate forecasts, including various market types and their sub-indexes.It is hypothesized in H_3 that including an explanatory variable would positively influence the accuracy of the forecasting freight rates. As expected, it decreases forecasting error in the log (RMSE) estimates and agrees with the findings of Lyridis et al. [25] and Yang and Mehmed [7]. However, log (MAPE) estimates

Table 2. *Meta-regression estimates for freight forecasting accuracy*

Model / Variable	RMSE OLS	RMSE WLS	RMSE Quantile 10th quant	RMSE Quantile 25th quant	RMSE Quantile 50th quant	RMSE Quantile 75th quant	RMSE Quantile 90th quant	MAPE OLS	MAPE WLS	MAPE Quantile 10th quant	MAPE Quantile 25th quant	MAPE Quantile 50th quant	MAPE Quantile 75th quant	MAPE Quantile 90th quant
Intercept	**5.1103*** (0.904)**	**5.2544*** (0.911)**	4.8191*** (0.425)	4.3663 (0.494)	**3.0152*** (0.360)**	3.9429*** (0.711)	6.7039*** (0.498)	**1.3082*** (0.726)**	**1.7347* (0.724)**	-0.8683 (0.738)	0.7074 (0.515)	**1.6125*** (0.664)**	1.9069 (0.747)	1.7346*** (1.050)
Forecast Periodicity														
Daily	**-0.969** (0.4137)**	**-0.9111*** (0.413)**	0.8737*** (0.177)	0.3563*** (0.215)	**-1.4276*** (0.165)**	0.7326** (0.366)	2.2784*** (0.298)	**-3.0080*** (0.287)**	**-3.0106*** (0.274)**	-4.3857*** (0.330)	-3.1664*** (0.221)	**-2.7285*** (0.262)**	-2.2313 (0.244)	-2.6545*** (0.250)
Weekly	**-0.574 (0.363)**	**-0.7985* (0.343)**	2.3973*** (0.158)	1.9616*** (0.180)	**-0.0995 (0.145)**	-0.2503 (0.310)	-1.4951*** (0.245)	**-1.3579*** (0.234)**	**-1.2813*** (0.214)**	-2.1545*** (0.230)	-1.3654*** (0.166)	**-0.9881*** (0.214)**	-0.7328 (0.205)	-0.4840** (0.219)
Yearly	**3.5011*** (0.866)**	**3.4690*** (0.887)**	3.0223*** (0.370)	2.9663*** (0.488)	**5.9387*** (0.345)**	4.9953*** (0.631)	5.4549*** (0.768)	**3.6610*** (0.9618)**	**3.5361*** (0.918)**	1.2757 (1.750)	1.6652* (0.888)	**5.4682*** (0.878)**	5.5117 (1.016)	6.0595*** (1.585)
Forecasting Horizon														
Short-run	**2.3288*** (0.252)**	**2.5886*** (0.259)**	-0.5669*** (0.106)	-0.4431*** (0.131)	**1.8474*** (0.101)**	3.5174*** (0.213)	6.5900*** (0.203)	**-0.2314 (0.196)**	**-0.1601 (0.196)**	-0.1003 (0.185)	-0.1901 (0.135)	**-0.3273* (0.180)**	-0.1448 (0.182)	0.0405 (0.213)
Long-run	**0.6337* (0.281)**	**0.6814** (0.291)**	-0.1583 (0.123)	-0.0896 (0.151)	**-0.0619 (0.112)**	0.3654* (0.207)	-0.0451 (0.181)	**-1.4729 (0.908)**	**-1.2351 (0.860)**	-1.2840 (1.727)	-1.5110* (0.863)	**-1.4430* (0.830)**	-1.6954 (0.951)	-2.5837* (1.551)
Forecasting Method														
Econometric	**-2.5154*** (0.354)**	**-2.3407*** (0.345)**	-2.0184*** (0.168)	-3.1719*** (0.189)	**-4.0988*** (0.141)**	-2.1509*** (0.309)	0.0233 (0.305)	**0.2137 (0.193)**	**0.1953 (0.192)**	-0.7073** (0.227)	0.0862 (0.152)	**0.4733*** (0.177)**	0.7821 (0.159)	1.0948*** (0.161)
Soft Computing	**0.4488 (0.367)**	**0.4526 (0.354)**	0.5747*** (0.159)	0.6838*** (0.189)	**0.1630 (0.146)**	0.1937 (0.283)	0.6977** (0.238)	**0.7595*** (0.169)**	**0.7727*** (0.164)**	0.3859** (0.178)	0.3818*** (0.132)	**0.5690*** (0.155)**	0.7149 (0.138)	0.8849*** (0.145)
Type of the Market														
Dry market	**2.4293*** (0.254)**	**2.7718*** (0.267)**	4.3894*** (0.082)	3.9442*** (0.113)	**3.3189*** (0.101)**	2.5365*** (0.243)	1.5864*** (0.207)	**-2.0837*** (0.464)**	**-2.3866*** (0.468)**	-1.1470** (0.422)	-1.575*** (0.312)	**-2.1359*** (0.424)**	-2.4023 (0.500)	-3.2756*** (0.724)
Container	**-0.0646 (0.596)**	**0.3556 (0.571)**	-1.8540*** (0.239)	-2.0694*** (0.294)	**-0.7474*** (0.237)**	-0.0216 (0.501)	0.9220** (0.415)	**-1.5257*** (0.451)**	**-1.7208*** (0.454)**	-0.8238* (0.449)	-1.2889*** (0.321)	**-1.7198*** (0.412)**	-1.9493 (0.434)	-3.4061*** (0.575)
Other Characteristics														
Sample size[a]	**-0.994*** (0.155)**	**-1.1050*** (0.153)**	-1.6207*** (0.080)	-1.2118*** (0.103)	**-0.6285*** (0.062)**	-0.8971*** (0.137)	-1.6102*** (0.116)	**-0.1627* (0.080)**	**-0.2029* (0.081)**	0.0342 (0.096)	-0.2002*** (0.063)	**-0.2442*** (0.073)**	-0.2379 (0.070)	-0.0060 (0.078)
Explanatory variables	**-2.8542*** (0.232)**	**-2.9819*** (0.237)**	-0.2179*** (0.076)	-0.3792*** (0.103)	**-0.5333*** (0.092)**	-1.2762*** (0.230)	-0.6624*** (0.183)	**1.4776*** (0.329)**	**1.3371*** (0.319)**	2.2041*** (0.321)	1.6726*** (0.221)	**1.3470*** (0.301)**	1.4833 (0.347)	1.9350*** (0.501)
Estimation Summary Statistics														
F-Statistic (p-value)	118.7*** (0.0000)	138*** (0.0000)	-	-	-	-	-	58.7*** (0.000)	59.94*** (0.000)	-	-	-	-	-
Breush-Pagan test (p-value)	135.63*** (0.000)	-	-	-	-	-	-	44.46*** (0.000)	-	-	-	-	-	-
AdjR²	0.5964	0.6324	-	-	-	-	-	0.6977	0.702	-	-	-	-	-
Pseudo R²	-	-	0.4789	0.42338	0.4147	0.4664	0.4689	-	-	0.4948	0.5276	0.5251	0.5232	0.5453
Number of Observations	878	878	878	878	878	878	878	276	276	276	276	276	276	276

***, ** and * indicate statistical significance at the 99%, 95% and 90% confidence levels, respectively. Standard errors are presented in parentheses below coefficient estimates.

[a]Log transformation of sample values

yielded contradictory results. This may be attributed to the information loss mentioned above. However, a closer examination of this difference is needed to identify the reasons for the negative impact in MAPE estimation.For forecasting horizon (H_4), Log (RMSE) estimations reveal positive and significant coefficients in short-run forecasts at 99% confidence level (OLS, WLS, and QR 50th models), but not in long-run forecasts at 90% confidence level (OLS, WLS, and QR 50th models) in forecasting horizon (H_4) (OLS and WLS models). There is no significant difference in forecasting accuracy between the OLS and WLS estimates of log (MAPE). The QR 50th model, on the other hand, has negative and statistically significant coefficients in both horizons at a 90% confidence level.

The log (RMSE) and log (MAPE) findings imply that short-run forecasts provide less accurate forecasts than long-term ones. However, this finding contradicts the theoretical expectations and assumption of previous findings wherein the accuracy of the forecasting models tends to decline with a longer forecasting horizon e.g. [30]. This implies the short-term horizon of the freight rate yields less accurate forecasts than the long-term horizon. This unexpected result stems from the nature of the freight forecasting studies attributed to the number of studies and the models used. The studies on freight rates have mainly focused on medium to long-term forecast horizons [24]. Similarly, the usage of dynamic models could be the other reason for this result, as dynamic econometric models provide better forecasts for longer horizons [33]. The results of the H_5 prove with a negative and highly correlated coefficient that the sample size influences the forecasting accuracy. This finding is consistent with the popular argument that larger sample sizes should reduce the accuracy of freight rate forecasting, as suggested by Sebri [30]. However, it should be noted that there are conflicting findings in previous studies wherein large sample sizes did not necessarily increase accuracy rate, and in some instances, yielded worse results.

The results support the hypothesis (H_6), where the forecasting accuracy of freight rate forecasts depends on data frequency. Daily and weekly data have negative signed coefficients, while annual data have positive coefficients. However, previous literature in the forecasting practice of other industries stating that forecasting with annual data presents more accurate forecasts [30]. It is reported that lower frequency data (yearly, quarterly, and monthly) tend to produce higher forecasting accuracies due to the complex seasonal characteristics of the high-frequency data (weekly, daily, and hourly). Freight rate forecasting studies generally consist of daily, weekly, monthly, and yearly data. Even though shipping markets are subject to recurrent heavy seasonality, we found that the forecasting accuracy of freight rate forecasting increased when the higher frequency data was employed. However, this unexpected result stems from the nature of the freight forecasting studies. Daily and weekly forecasts are required more frequently than quarterly or yearly ones in this context. The studies on freight rates have mainly focused on high-frequency data and these forecasts are used for supporting short-term strategic decisions.

5. Conclusion and Implications for Future Research

In this study, we aimed at revealing the patterns of obtaining accurate freight rate forecasts by identifying quantitative explanations using Meta-Regression methodology. Recently, Duru et al. [3] reported the need to identify the influencers of freight rate forecasting to achieve accurate and reliable forecasts. However, no previous statistical and quantitative review has been carried out to the best of our knowledge on this issue. This motivates us to conduct a Meta-Regression to contribute to the growing literature of freight rate forecasting by providing robust and novel empirical evidence revealing the determinants of forecast accuracy. The results confirm that data frequency, forecasting horizon and method, market type, sample size, and inclusion of the explanatory variables significantly affect the accuracy of the freight rate forecasts. The research also summarizes the state-of-the-art freight rate forecasting literature and builds future research directions for this important topic.

We conducted a detailed analysis of the literature using quantitative approaches, considering the extensive research on freight rate forecasting. For the first time, a comprehensive data set is collected, including 878 observations for RMSE and 276 observations for MAPE, and Meta-Regression is used to determine the influencing variables. The main contribution of the study is twofold: first, it compares quantile regression, a robust alternative, to OLS and WLS. The results of this study are more robust because it presented many estimates and used more than one accuracy metric. Second, this study adds to previous reviews by providing quantitative evidence.

As far as the policy implications of this study are concerned, this study argues that the shipping industry is highly volatile and unpredictable due to the dependence on exogenous factors such as complexity, cycles, extreme times, and developments of the world economy, and irrational decisions of the market players. Therefore, there is no chance of success for point forecasting in the industry. When forecasting freight rates, we suggest policymakers, forecasters, and other market players consider employing daily data, explanatory variables, data for submarkets and different routes, small sample size, and long-term horizon while developing their forecasting models. It should be noted that these results should be considered as auxiliary and that such models are case-specific and subject to change. Each attempt based on hyperparameter optimization or daily performance dynamic combination forecasts are also used to govern such method shifts. Ideally, their use is recommended in conjunction with empirical knowledge. Even if forecasting practices' experiments include various methods and different hyperparameters during the model development, this study could suggest a starting point. Moreover, it was detected that qualitative forecasts had been encountered in freight rate forecasting literature infrequently. We also suggest that a tendency to focus on qualitative studies might increase the accuracy of the freight rate forecasts. This supports the implications of Munim and Schramm [18]. Although Schramm and Munim [34] recently attempted to integrate judgements into the forecasting practice, more research is required in this domain.

Our research is expected to be of value to industry practitioners and scholars as it reveals a deeper understanding on the effects of influencing variables on the freight rate forecasting model and thus helps to clarify the model development stage. Although researchers and practitioners in the shipping industry tend to agree that freight rate forecasting is important, there are contrasting views on how different models with various specifications are considered in different circumstances. We provide a synthesis of the growing, but diverged, literature on freight rate forecasting through this Meta-Regression analysis. The results inform about important influencers of the accurate freight rate forecasting models and their effects. These results can serve as a basis for future freight rate forecasting studies as for developing their models.

This study, like all others, has some limitations. A constraint could be publication bias, which evaluates only published articles. As a result, the future inclusion of unpublished studies may improve the reliability of Meta-Regression analysis. Due to sample limitations, it should be necessary to re-evaluate the influencers' impacts in the future as the number of relevant studies increases over time. Furthermore, we divided the forecasting techniques into three categories for the purpose of this study, but; however, future studies may include additional approach subclassification if the sample size grows significantly. Despite the large number of studies and observations examined in this study, only the MAPE and RMSE metrics were examined. Future research is encouraged to publish additional forecasting measures that can be used to benchmark findings. Another limitation is that we did not consider the number of explanatory variables, the lag, or the country of publication of the freight rate forecasting research. In the future, studies may investigate this issue as well.

Authorship Contributions

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