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About the JEMS

Aim:

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.

Scope:

Scope of the journal covers national, international and local studies regarding Marine Engineering, Marine Transportation Engineering, Naval Architecture Engineering, Marine Operations, Logistics, Logistics Engineering, Maritime History, Coastal Engineering, Marine Pollution and Environment, Fishing and Fisheries Technology, Shipbuilding and Ocean Engineering.

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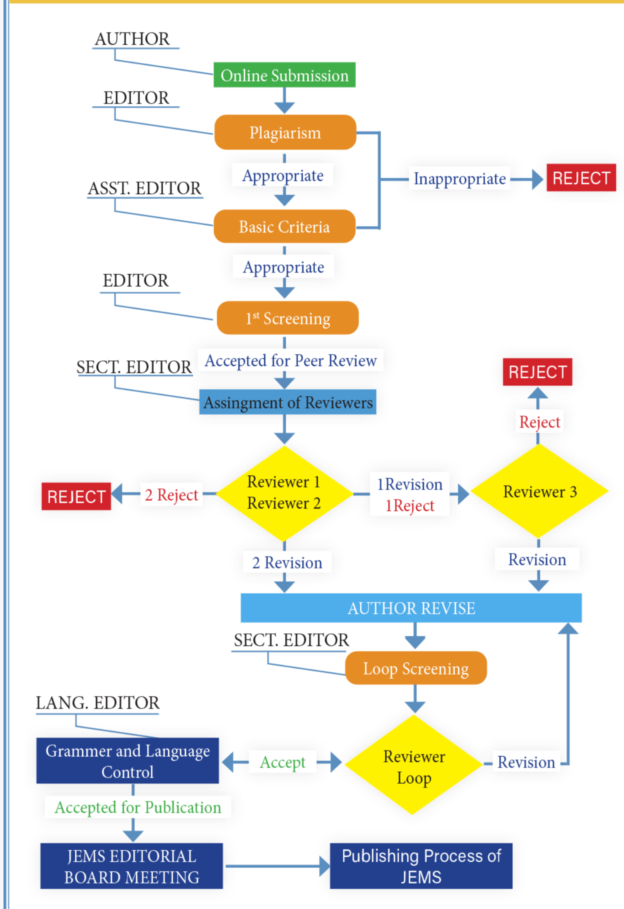

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Abstract

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.

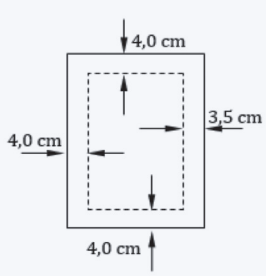
Keywords: JEMS, Author, Manuscript, Guide

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

2. Page Layout and Format

JEMS publishes studies conducted in **English**. Text is to be prepared with justified alignment, without indentation in the paragraph beginning, in **"Cambria"** format with **10-point** font size and **1,0** line- spacing. There must be **initially 6nk and then 3nk** line spacing between the new launching paragraph and the previous paragraph. Worksheets must be on **A4** paper size, and margins should b**e 4 cm from the top, 4 cm from the bottom, 4 cm from left** and **3.5 cm from right**.



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

The first letter of the primary headings in the article should be capital letters. All headings and sub-headings should be designed **10 pt, bold** and **located to the left** with **numbering**, and also navy blue color should be used for sub-headings.

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

1.1 Axis Team

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

Report (RP) Interview (RP)

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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Book Review (BK)

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

Academic Perspective

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).

Industrial Perspective

An article in conformance with a specified text format prepared by an expert as an invitee whose knowledge and experience related to their area of expertise is recognized 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).

5. References

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

The IEEE Style is used for publications in engineering, electronics, telecommunications, computer science and information technology.

IEEE Style uses a notational method of referencing when referring to a source of information within the text of a document.

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

JEMS Ethics Statement

JEMS Publication Ethics And Malpractice Statement

ournal of ETA Maritime Science is an independent publication regarding scientific research, and the editor decides its publication policy. The statement signifies the ethical behaviour of the publisher, the editor, the reviewers and the authors. The ethics statement for JEMS is based on ***COPE Code of Conduct and Best Practice Guidelines for Journal Editors and COPE Best Practice Guidelines for Journal Editors*** available at www.publicationethics.org.

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Duties of the Publisher

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A submitted manuscript should be original, and the authors ensure that the manuscript has never been published previously in any journal. Data of the research ought to be represented literally in the article. A manuscript ought to include adequate detail and references to allow others to replicate the study.

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The authors who want to submit their study to the journal must ensure that their study is entirely original. The words and sentences getting from the literature should be appropriately cited.

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Convenient acknowledgement of the study of others has to be given. Authors ought to cite publications that have been efficient in determining the study. All of the sources that used the process of the study should be remarked.

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Authorship of a paper ought to be limited to those who have made a noteworthy contribution to the study. If others have participated process of the research, they should be listed as contributors. Authorship also includes a corresponding author who is in communication with the editor of a journal. The corresponding author should ensure that all appropriate co-authors are included in a paper.

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Contents

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Journal of ETA Maritime Science 2021;9(4):221-221

Research Environment After COVID-19

Selçuk Nas

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

Keywords

Research, Environment, COVID-19

We all experienced the impacts of the COVID-19 pandemic on the maritime academic research in 2020 and 2021. The most significant of these impacts were the slowing down or stopping of field research activities, creation of new research topics and opportunities, and collaborations using remote access technologies. The Chamber of Marine Engineers, the owner of Journal of ETA Maritime Science (JEMS), has turned remote access technologies into opportunities under the pandemic conditions. The Global Conference on Innovation in Marine Technology and Future of Maritime Transportation (GMC) series, which was traditionally organized by The Chamber of Marine Engineers, was held online on November 18-19, 2021, and organized by the University of Strathclyde (UK), Constanta Maritime University (Romania), and Iskenderun Technical University (Turkey). The GMC'21 conference was attended by more participants than expected. In this issue, Prof. Osman TURAN, Advisory Board member of JEMS, shared his valuable impressions about the conference with our readers in his After Meeting article.

At the end of 2021, when COVID-19 new variant threats continue, we are witnessing a revival of the research climate as restrictions ease off. We also see that the interest in our journal is increasing every day. As a result of this interest, we are sharing interesting original research articles with our readers in the JEMS 9 (4) issue. 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.

Address for Correspondence: Selçuk Nas, Dokuz Eylül University Maritime Faculty, Department of Maritime Education and Training, İzmir, Turkey
E-mail: snas@deu.edu.tr
ORCID ID: orcid.org/0000-0001-5053-4594

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Journal of ETA Maritime Science 2021;9(4):222-232

Effect of Business Operation Period on the Relationship Between Knowledge Management Applications and Ship Performance

Murat Yorulmaz[1], Ahmet Karabacak[2]

[1]Kocaeli University Maritime Faculty, Department of Maritime Business Administration, Kocaeli, Turkey
[2]Directorate General of Coastal Safety, İzmir, Turkey

Abstract

This study aims to examine the effect of knowledge management (KM) on the cargo performance (CP) and navigational performance (NP) of ships and to determine whether the business operation period of the firm has a moderating effect in this relationship by means of KM applications used in businesses operating in international markets. This work also investigates the impact of the business operation period on the ship's CP and NP. Data were obtained by administering a questionnaire to 451 employees who work in a total of 67 ship businesses operating in Turkey and analyzed using SPSS 22 Hayes (2019) Process macro (v3.4) and AMOS 22 programs. Findings indicated that the KM applied in ship businesses has a positive effect on both performances of ships, explaining about 17% and 13% of the change in their navigation performance and CP, respectively. This study concluded with suggestions to the managers of ship businesses on how to render their KM applications more efficiently and effectively.

Keywords

Knowledge management, Navigational performance, Cargo performance, Ship performance, Ship management, Maritime business

1. Introduction

Knowledge management (KM), which involves acquiring, transforming, and applying knowledge [1], requires a company-wide strategy that includes the knowledge available when and where it is needed, ensuring the availability from external and internal sources. This includes the process of continuously managing all kinds of knowledge and their implementation, monitoring, and evaluation [2]. KM seeks to ensure that an organization gains awareness of the knowledge it has, either on an individual basis or a collective basis, and transforms itself to use the knowledge it possesses or can acquire most effectively and efficiently. Thus, this makes it a pivotal factor in making organizations competitively advantageous in volatile markets [3]. For an organization to be able to adapt to changing conditions, it must acquire knowledge from different sources and transform them into an application process to use the acquired knowledge in line with its goals and activities [4]. In the narrowest sense, KM, involving various activities, consists of five main processes: creating, storing, possessing, transferring, and implementing knowledge [5]. KM applications, the most important process of KM, aim to combine corporate memories in the form of corporate intranets to improve the knowledge of the organization and consequently enhance the quality of the service provided to customers and users [6]. This facilitates observing and improving the value, benefit, and contribution of the acquired knowledge. Maritime transportation, carrying more than 80% of the global trade volume, continues to be the backbone of the global trade and manufacturing supply chain. The world maritime transportation, which was 2,605 million tons in the 1970s, has reached 11,005 million tons as of the end of 2018 [7]. KM has increasing importance in maritime transportation, which offers large-scale services and has its own dynamics. Ports, maritime businesses, and

Address for Correspondence: Murat Yorulmaz, Kocaeli University Maritime Faculty, Department of Maritime Business Administration, Kocaeli, Turkey
E-mail: murat.yorulmaz@kocaeli.edu.tr
ORCID ID: orcid.org/0000-0002-5736-9146

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intermediary firms, which seemed independent from each other in the past, urge all stakeholders to work efficiently and effectively among each other to meet their needs with the integration of technology boosted by globalization. Therefore, the value and success of maritime businesses at the center of the logistics system depend on how well they react to the demands of their customers in the logistics system by correctly managing the flow of goods, services, and knowledge, making this a strategic issue for businesses [8]. KM applications both enhance the service quality of maritime transportation companies that control maritime transport, which is essential for commercial activities, and improve their performance by providing them with a competitive advantage. A study that was simultaneously performed in the production and service sector in three different countries indicated that KM applications increase the competitiveness and economic performance of companies [9]. Research conducted in different sectors revealed that it would allow for more efficient use of resources and consequently a more innovative and better performance [10]. Moreover, it also contributes to the organizational performance of the production, finance, and service sectors [11], enhances the organizational performance in software companies [12], supports the performance of nurses, and minimizes hospital expenses in the health sector [13].

Although many studies on the effect of KM applications on organizational performance are available, research in the maritime field is limited. This study is of great significance as it seeks to address a research gap in the literature and to evaluate ship performance (SP) based on a different method. This work aims to examine the relationship between KM applications in internationally operating shipping companies and the navigational and cargo performances (CPs) of ships and to reveal whether the activity period of the firm has a moderating effect in this relationship.

2. Literature Review and Hypotheses

2.1. Knowledge Management

Acquisitions resulting from the interaction of humans with concrete or abstract objects are called knowledge [14], and people have an unlimited ability to produce knowledge [15]. The knowledge produced through experiences can only be beneficial if it is used correctly in the interests of the individual and of the community. In addition to social and collaborative processes, knowledge is formed, shared, strengthened, enhanced, and justified through the cognitive processes of individuals [16]. Among the two basic types of knowledge (i.e., implicit knowledge and explicit knowledge) in organizations and individuals, the most valuable and remarkable type is the implicit knowledge, which is in the mind of the individual [17]. New knowledge is generated from existing knowledge by transforming it with the implicit and explicit knowledge of the organization or by developing the content [18]. The internalization process of knowledge, one of the most critical processes in the KM application, is the process of developing the knowledge that is explicit by integrating it with the implicit knowledge of the organization's employees and thus turning it back into implicit knowledge [19]. The internalization of knowledge is the process of integrating and synthesizing explicit knowledge through experience, and organizations must make it accessible to facilitate the internalization of knowledge among organization members to enhance the value of their knowledge [20]. The most pivotal factor in the development, dissemination, and benefit of knowledge is that knowledge becomes open, i.e., it is shared. Knowledge exchange among organizational staff members is an essential component in the KM process, but developments in modern information and communication technology eliminate and facilitate time and distance limits for such exchanges [21]. Knowledge shared among the most basic level employees in organizations is seen as an important strategic resource for organizations. Therefore, the proper management of this resource is critical to the corporate's success, which is related to the formation, sharing, and usage of knowledge within the organization [22]. Knowledge sharing is different than communication or knowledge distribution as it occurs between two parties, one of whom communicates knowledge either consciously or not, by acts, by speech, or in writing, etc., while the other should be able to perceive these expressions of knowledge and make sense of them [23]. In this context, healthy knowledge sharing is only possible when the shared knowledge is positioned and evaluated by stakeholders with the same perspective, something beyond knowledge transfer (KT). Knowledge acquired, internalized, and shared can only be beneficial if it is implemented and used. The application and use of knowledge refer to the process where knowledge is utilized in making decisions or policies [24]. For this reason, when a business fails to implement and utilize its sources of information efficiently and effectively, its abilities in creating, storing, and sharing these sources become useless and the KM process loses its significance.

2.2. Performance

Outside of any specific context, performance can be associated with the completion of a range of acts, from simple and mundane acts, momentary or short-term, to long-term and more detailed acts [25]. According to Dooren et al. [26], performance, which can be expressed as sustainable results that are conceptualized by considering the quality of actions and achievements, refers to the productive organization, or in other words, the process that includes the entire value chain from inputs over outputs to results. Therefore, in broader terms, performance can be described as being able to complete a pre-planned act within a specific time. However, it is possible to define organizational performance as the degree to which businesses achieve their goals [27]. Organizational performance assessed within the framework of the activities of organizations can be considered at different levels: the cost of producing a designated product using a product or the efficiency of performing a particular task [28]. For organizations that can be considered in two groups according to their purposes as financial and non-financial, organizational performance is entirely related to the structure of the organization and is about achieving the goals the organization defines within its own framework [29]. In this context, the definition of organizational performance, which does not offer a sound assessment method, may differ across different disciplines. The level of organizational performance depends on employee satisfaction, organizational commitment, motivation, and feelings of organizational citizenship, and individual factors [30]. Performances of ships, which have hierarchical structures just like an organization, are important for maritime businesses. The prediction of the navigational performance (NP) of ships is linked to the interaction of ships with the resistance they encounter during the voyage. Routes determined using the software designed for voyage optimization are intended to enhance NP. The optimum route is described as the route that has the least fuel consumption, taking into consideration the average ship's speed, sea conditions to be encountered, and the voyage period [31]. For a long time, performance has been assessed using relatively simple procedures. These procedures report the fuel consumption daily as well as the distance that a ship traveled within 24 hours in the "Noon Report," which includes the average speed observed and weather observations. Performance is a measure of the energy consumption in a particular state, namely speed, ship cargo condition, weather, and other factors (waves, shallow water, changes in seawater temperature, etc.), and will decrease over the life of the ship [32]. In merchant ships, which primarily seek to carry cargo, the SP depends on two main activities: navigational activities where processes related to route, maneuvering, direction, and position are performed to allow ships to move safely between specified ports, and operations involving balance, stress, loading, and unloading of the cargo shipped [33]. That said, one of the prominent factors that are influential in the performance of a ship is possibly the cargo operations that determine the draught, trim, and aerodynamic structure of the vessel. Another influential factor is the geographical area involving external factors that affect this structure such as currents, winds, and temperatures.

Through performance measurement systems, an organization can track the progress it made toward its objectives and thereby understand its current status, the key issues that need to be addressed, and the available options [34]. Therefore, measuring, analyzing, and interpreting the performance of a business with the right methods is as important and necessary as the performance of the business. Studies on the measurement of the ship's performance mainly focus on the energy efficiency, bunker consumption, propeller, and engine performance obtained by quantitative methods [35-41]. Unlike these studies, the performance of five ships of Turkish maritime lines, operating in the dry cargo market in Turkey, was measured using the effectiveness and performance measurement criteria (*key performance indicators*, KPI), which were developed by the MARINTEK Institute. It was concluded that the environmental and health-safety-related navigational and operational performances of maritime lines are sufficient, but the technical performance is poor [42]. Another study conducted with four different ships employed in a short-distance freight transport of four shipping companies revealed that ships of companies that use outsourcing in their management perform better according to KPI standards [43]. This present study, based on the definition of performance, seeks to evaluate the cargo and NPs of ships, which is a process extending from inputs to outputs and results, by drawing on the perceptions of the employees.

2.3. Relationship Between KM and Performance

Studies on KM and performance in various fields are available in the literature. A study with 314 executives in the trade and service sector found that KM processes had a positive and significant effect on innovation performance, although knowledge hoarding harmed this performance [44]. The integrative relationship between flexibility and organizational performance was examined in 838 companies in the industry and service sector in Spain with 15 or more employees, revealing that KM had a positive effect on organizational performance [45]. In Bahrain, a study conducted with 119 human resources managers and general managers in companies operating in the service sector, including sectors such as health, accounting, transportation, retail, hotel, educational institutions, and consultancy services, determined that the KM process had a positive correlation with the organizational performance [46]. Another study performed with 151 people on the impact of the KM process (collecting, transforming, using, and protecting knowledge) on the organizational performance in the finance sector indicated a positive relationship only between using and protecting knowledge and organizational performance [47]. Another study was carried out in 270 public businesses across the United

Arab Emirates, revealing that KM processes have varying impacts on performance. In other words, the KM process has its strongest effect on innovative performance, followed by concepts of quality and operational performance [48]. Research with post-graduate students at the University of Delhi, India, found that the KM system has a direct and significant impact on the student's performance [49]. In addition, a study with senior executives of 69 companies that provide ocean freight services registered in the Korea International Freight Forwarding Association, determined that KM in logistic companies enhanced the organizational performance. It was further revealed that companies carrying out maritime transportation obtain information in cooperation with companies both within internal and external sources and manage information effectively to improve their corporate performance. Results show that the information of maritime companies is a decisive resource to increase their logistics value and innovative capability [50]. Another study with 83 managers registered in the National Maritime Agents and Companies Association, operating internationally in the regular line transportation in Taiwan determined that KM is positively associated with innovation and that there is a positive relationship between the KM culture and innovation, financial, and customer service performances of organizations. It also revealed that information technology does not directly support all kinds of corporate performance, and the organizational structure and KM culture are found to be related to corporate performance such as innovation, finance, and customer service [51]. The literature review showed that KM applications have an important and positive effect on performance. Hence, hypothesis 1 and hypothesis 2 were proposed.

Hypothesis 1: KM applications in ship businesses positively affect navigation performance.

Hypothesis 2: KM applications in ship businesses positively affect CP.

Some studies on KM and performance tested and assessed different concepts that have a moderating role between or are believed to have a direct role on KM and performance. The effect of the demographic characteristics and KM providers of construction companies on the firm performance was investigated in a study with 105 large-scale construction companies operating in the construction industry in Turkey, 54 of which are members of the Contractors' Association. Statistically evaluated findings showed that there was a positive and significant relationship between the technological KM and structural KM providers and the performance of construction companies, but there was no positive and significant relationship between the cultural KM provider and the performance of the construction company. A two-step hierarchical multiple regression analysis revealed that the firm's age and size cannot statistically affect the firm's performance and that they do not have a statistically significant relationship with the organization's performance [52]. Face-to-face surveys with managers working in the accounting department of 53 small and mid-size enterprises demonstrated that there is a statistically significant difference between the level at which they use the knowledge obtained from databases of other units in accounting-related tasks and the establishment year of the business and the number of employees in the business [53]. Based on these studies, hypothesis 3 and hypothesis 4 were proposed:

Hypothesis 3: The business operation period (BOP) has a moderating role in the effect of KM applications on the navigation performance in ship businesses.

Hypothesis 4: The BOP has a moderating role in the effect of KM applications on the CP in ship businesses.

Figure 1 shows the research model designed considering the hypotheses proposed above in light of the discussed information.

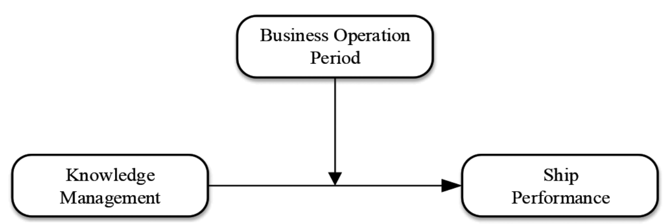

Figure 1. *Research model*

3. Materials and Methods

3.1. Sampling and Data Collection

Data were obtained using the questionnaire method to determine the effect of KM applications in ship operations on the NP and CP of ships and whether the operation period of the firm has a moderating role in this interaction. Questionnaires were applied face-to-face and through e-mail to the employees of 67 volunteer ship businesses in Turkey between September 2019 and March 2020. Data from 451 questionnaires that were filled in completely and correctly were used for the analysis.

Most of the participating ship management employees are male (365 participants, 80.9%). Two hundred and six (45.7%) of them are aged 35-45 years, while 14 (3.1%) are aged 20-25 years. Two hundred and ninety-four of the employees (65.2%) are university graduates. Hundred and five employees (23.3%) work in the technical department, 93 (20.6%) work in the human resources department, and 67 (14.9%) serve in the operation department. One hundred and thirty-five employees (29.9%) are managers including those of the lower level, middle level, and top level. Of the employees, 109 (24.2%) have 4-7 years of work experience, whereas 60 (13.3%) have 3 years or less of work experience. Also, 203 (45%) of the employees work in the dry cargo market and 39 (8.6%) work in the Ro-Ro market in the ship business with an average year of activity of 12.4 years.

3.2. Measures

The validity and reliability of all measurement tools used to collect data in this study were tested in previous studies, and items in the scale were arranged using the 5-point Likert rating scale (1=strongly disagree; 5=strongly agree).

3.2.1. KM Scale

A 20-item scale (Cronbach's Alpha > 0.70), with dimensions of KT (e.g., "There is a culture that encourages knowledge sharing"), knowledge applications (e.g., "To benefit from knowledge resources, information is transferred to application areas"), knowledge creating (e.g., "I can generate new knowledge from existing business data"), and knowledge storing (e.g., "I systematically store the knowledge necessary for the job"), was used as a KM scale. The scale, originally developed by Lee et al. [54], was adapted to Turkish and tested for validity and reliability by Çetinkaya [55]. Since the four items were idle or loaded to more than one dimension in the explanatory factor analysis (EFA) that was carried out using the principal components analysis and the Varimax rotation technique to determine the consistency of the scale, these items were removed. Results of the analysis showed that the KM scale has a four-dimensional structure with eigenvalues greater than 1 [Kaiser-Meyer-Olkin (KMO)=0.833; χ^2=2476.660; df=120; p<0.001; factor loads range from 0.596-0.855; total explained variance: 67.8%].

3.2.2. SP Scale

A two-dimensional, namely NP (e.g., "The voyage planning is done quickly and without errors") and CP (e.g., "Knowledge about the cargo is delivered to the ships on time and quickly"), and eight-item scale (Cronbach's Alpha>0.65) developed by Yorulmaz [33] was used to measure the SP. The EFA, which was performed to determine the consistency of the scale using the principal components analysis and the Varimax rotation technique, showed that the scale has a two-dimensional structure with eigenvalues greater than 1 (KMO=0.768; χ^2=901.495; df=28; p<0.001; factor loads range from 0.598-0.827; total explained variance: 62.3%).

3.3. Analysis Methods

Data obtained through surveys were analyzed using SPSS 22 and AMOS 22 statistical package programs. Discriminant and convergent validities were used to determine the validity of the measurement model, and Cronbach's alpha and composite reliability (CR) coefficients were used to determine the reliability of the measurement model. The structural equation modeling used for path analysis with AMOS 22 and the Bootstrap based on 5000 samples was utilized for the analysis of the moderating role, and the SPSS 22 Hayes (2019) Process macro (v3.4) plugin was used.

4. Results

4.1. Validity and Reliability Analysis

A confirmatory factor analysis (CFA) was performed to measure the validity and reliability of the measurement model. Results determined that standardized factor loads of the variables observed were greater than 0.50 and statistically significant [standardized β: 0.606-0.846; p<0.001]. However, goodness-of-fit values of the measurement model [χ^2/df=2,020; comparative fit index (CFI)=0.931; tucker-lewis index (TLI)=0.917; root mean square error of approximation (RMSEA)=0.048; standardized root mean square residual (SRMR)=0.025] were within acceptable limits [56,57]. For the convergent validity of the scales in the measurement model, the average variance extracted (AVE) and CR values were calculated, and the square root values of the AVE were calculated for the discriminant validity. Tables 1-3 show the results.

Evident in Table 1, results confirmed the convergent validity of the measurement model as the AVE values of all factors were greater than the critical value (0.50), and CR values, which exhibited values greater than the threshold value (0.70), were greater than the AVE values [57,58].

Table 2 shows that relationships between all factors were significant (p<0.01). The divergent validity was confirmed because the AVE square root values were greater than the Pearson correlation coefficients between the factors [57] and also because the correlation coefficients were less than 0.85 [59]. However, Table 1 shows that the measurement tools are reliable [57] scales since the CR and CA values were greater than 0.70.

Values of CFA fit indices for the path analysis of the measurement model with confirmed validity and reliability are given in Table 3, where the second-order KM and first order SP CFA were used because the second-order CFA goodness-of-fit values for KM and the first order CFA goodness-of-fit values were more suitable for SP and for the research purposes.

Moreover, since the independent and dependent variables in the measurement tool were responded to by the same respondents at the same time, Harman's single factor test was carried out to determine the common method bias and particular attention was paid to the scale order to prevent it. In the first part of the survey, dimensions of the dependent variable SP were included in the SP and CP questions, and questions of the dependent variable KM were included in the second part of the survey to balance the order of the scale. Further, the EFA analysis, conducted with the principal components method and without rotation, yielded factor components with five factors and eigenvalues greater than 1 as well as the explained total variance of 52.2% with the first factor alone explaining 18.7% of the total variance. That is, there was more than one-factor structure in the said EFA analysis, and the first factor did not have a significant

Table 1. *Convergent validity and Cronbach's Alpha*

Factors	Observed variables	Standardized β	t-values	AVE	CR	CA
NP	NP1	0.846	10,526***	0.506	0.801	0.717
	NP2	0.606	8,460***			
	NP3	0.741	10,013***			
	NP4	0.626	-			
CP	CP1	0.666	9,987***	0.522	0.814	0.740
	CP2	0.737	10,217***			
	CP3	0.749	10,876***			
	CP4	0.736	-			
KT	KT1	0.662	9,910***	0.518	0.843	0.813
	KT2	0.748	12,478***			
	KT3	0.741	12,404***			
	KT4	0.682	11,128***			
	KT5	0.761	-			
KA	KA1	0.773	13,689***	0.525	0.792	0.776
	KA2	0.712	13,004***			
	KA3	0.689	10,899***			
	KA4	0.721	-			
KC	KC1	0.738	11,416***	0.518	0.811	0.759
	KC2	0.688	10,552***			
	KC3	0.777	11,772***			
	KC4	0.670	-			
KS	KS1	0.775	9,188***	0.636	0.840	0.742
	KS2	0.784	9,876***			
	KS3	0.832	10,243***			

***p<0.001

AVE: Average variance extracted, CR: Composite reliability, CA: Cronbach's Alpha, NP: Navigational performance, CP: Cargo performance, KT: Knowledge transfer, KA: Knowledge applications, KC: Knowledge creating, KS: Knowledge storing

Table 2. *Pearson correlation and square root of AVE*

Factor		1	2*	3	4	5	6	7
1. NP	0.711	-						
2. CP	0.722	0.382**	-					
3. KT	0.719	0.220**	0.250**	-				
4. KA	0.724	0.331**	0.279**	0.474**	-			
5. KC	0.719	0.217**	0.209**	0.316**	0.339**	-		
6. KS	0.797	0.207**	0.310**	0.332**	0.316**	0.340**	-	
7. KM	-	0.288**	0.291**	0.741**	0.742**	0.675**	0.710**	-

**p<0.01

AVE: Average variance extracted, NP: Navigational performance, CP: Cargo performance, KT: Knowledge transfer KM: Knowledge management, KA: Knowledge applications, KC: Knowledge creating, KS: Knowledge storing explanation in the total explained variance. Lastly, the CFA analysis, where all observed variables were handled with a single factor, was conducted. It can be argued that no common method variance bias occurred because the CFA of the single factor model (χ^2/df=8,120; CFI=0.473; TLI=0.423; RMSEA=0.126; SRMR=0.054) was far below the acceptable limits [60,61].

Prior to testing the research hypotheses, skewness, and kurtosis coefficients of the factors were calculated and variables were examined to see whether they had a normal distribution. Results and averages of the factors are given in Table 4 where the data showed a normal distribution [59], since the skewness coefficients were between -0.765 and -1.090, the kurtosis coefficients were between 0.316 and 2,404 and less than 3, and the critical values were less than 10.

4.2. Testing Hypotheses

Goodness-of-fit values of the path analysis (χ^2/df: 2,157; CFI: 0.919; TLI: 0.906; RMSEA: 0.051; SRMR=0.031) were within the acceptable limits [56,57] and were found by the structural equation modeling shown schematically in Figure 2 to reveal the impact of KM applications on the ship performance in ship operations. Results of the path analysis demonstrated that KM applications had a significant and positive effect on NP (std. β: 0.410; t: 5,008; p<0.001) and that KM explained approximately 17% of the change in NP (R^2: 16.9). Based on these findings, Hypothesis 1 was accepted. Likewise, KM applications had a significant and positive effect on CP (std. β: 0.360; t: 4,026; p<0.001), and KM explained about 13% of the change in CP (R^2: 13.1). Based on these findings, Hypothesis 2 was accepted.

The SPSS 22 Hayes [62] Process macro (v3.4) plugin was used to examine whether the BOP has a moderating effect in the relationship between the KM applications and the ship's NP and CP in ship businesses. Table 5 presents the results

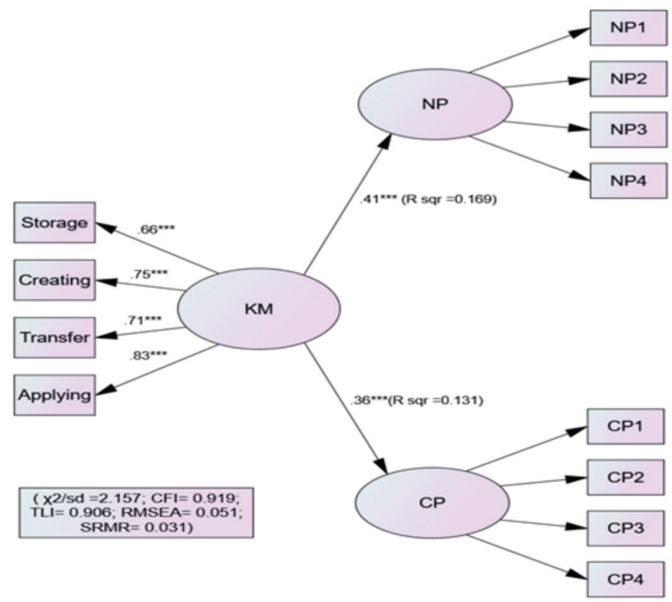

Figure 2. *Path analysis*

NP: Navigational performance, CP: Cargo performance, KM: Knowledge management, CFI: Comparative fit index, RMSEA: Root mean square error of approximation, SRMR: Standardized root mean square residual, TLI: Tucker-lewis index

Table 3. *Confirmatory factor analysis goodness-of-fit indices*

Scales	χ^2	df	χ^2/df	CFI	TLI	RMSEA	SRMR
First order KM	227,335	95	2,393	0.943	0.930	0.056	0.026
Second order KM	226,881	97	2,339	0.947	0.933	0.055	0.025
First order SP	32,758	16	2,047	0.981	0.967	0.048	0.017
Second order SP	80,129	17	4,713	0.928	0.882	0.091	0.025

RMSEA: Root mean square error of approximation, SRMR: Standardized root mean square residual, df: Degrees of freedom, KM: Knowledge management, SP: Ship performance, CFI: Comparative fit index, TLI: Tucker-lewis index

Table 4. *Means, standard deviations, skewness, and kurtosis*

Factors	Means	SD	Skewness	SE	Kurtosis	SE
1. NP	3,726	0.491	-0.881	0.115	1,139	0.229
2. CP	3,688	0.509	-0.890	0.115	1,691	0.229
3. KT	3,898	0.544	-0.808	0.115	0.708	0.229
4. KA	3,929	0.543	-0.868	0.115	0.721	0.229
5. KC	3,968	0.496	-0.765	0.115	0.316	0.229
6. KS	3,855	0.583	-1,090	0.115	2,404	0.229
7. KM	3,913	0.388	-0.801	0.115	1,215	0.229

SD: Standard deviation, NP: Navigational performance, CP: Cargo performance, KT: Knowledge transfer KM: Knowledge management, SE: Standard error, KA: Knowledge applications, KC: Knowledge creating, KS: Knowledge storing

Table 5. *Moderating effect test of NP and CP*

Variables	B	SE	t	p	95% CI LL UL	
(NP) Constant	4,477	0.022	200,205	0.000	4,383	4,470
KM	0.370	0.057	6,505	0.000	0.258	0.482
BOP	0.006	0.017	0.347	0.728	-0.028	0.040
KM*BOP	0.059	0.045	1.301	**0.193**	-0.030	0.148
Model 1 Sum.	R^2=0.093; F=15,364; p<0.001; ΔR^2=0.003					
(CP) Constant	4,387	0.023	186,083	0.000	4,341	4,433
KM	0.256	0.060	4,224	0.000	0.137	0.376
BOP	0.019	0.018	1,040	0.298	-0.017	0.056
KM*BOP	0.024	0.048	0.513	**0.607**	0.119	0.070
Model 2 Sum.	R^2=0.040; F=6,215; p<0.001; ΔR^2=0.0006					
CI: Confidence interval, LL: Lower limit; UL: Upper limit, NP & CP: Dependent variables, KM: Knowledge management, BOP: Business operation period, SE: Standard error						

of the moderating test performed by applying the Bootstrap 5000 resampling technique.

It is noted in Table 5 that models tested with the moderating effect analysis were statistically significant (Model 1 R^2=0.093; F=15,364; p<0.001) (Model 2 R^2=0.093; F=15,364; p<0.001), but the effect of the interaction term (KM*BOP) on both NP (B=0.059; t=1.301; p>0.05) and CP (B=0.024; t=-0.513; p>0.05) was not statistically significant. The fact that the interaction term was not statistically significant indicated that the BOP had no moderating effect on the relationship between the KM applications and the ship's NP and CP. Based on these findings, Hypothesis 3 and Hypothesis 4 were rejected.

5. Discussion

To determine the effect of KM applications in the ship management on the NP and CP of ships and whether the BOP has a moderating effect in this interaction, data were drawn from surveys with 451 employees of 67 ship managements in Turkey, which were then analyzed using SPSS 22 Hayes [62] Process macro (v3.4) and AMOS 22 programs. Results of the path analysis based on the structural equation modeling showed that the KM applied in ship managements both on NP (std. β: 0.410; t: 5,008; p<0.001) and on CP (std. β: 0.360; t: 4,026; p<0.001) had a significant and positive effect. This study also ascertained that the KM explained approximately 17% of the change in NP (R^2: 16.9) and approximately 13% of the change in CP (R^2: 13.1). Based on these findings, Hypothesis 1 and Hypothesis 2 were accepted.

These findings are congruent with studies in different sectors that pointed out the positive impact of KM on performance [44-49]. The knowledge available for use in sea transportation with a multidisciplinary structure, which operates 24/7, typically includes implicit information that seafarers have. The varying nature of factors to be encountered during the voyage period affects the performance of the ship. Thus, the variable implicit and explicit information on conditions such as cargo, port characteristics, weather conditions in the port, unknown information on sea and weather conditions during the voyage period, currents, and conditions related to the port of arrival, and traffic density play a decisive role in the performance of the ship. With the extending reach of information technologies and the adaptation of innovations to ships, the knowledge flow between ships and the second and third institutions such as the operation, receiver, charterer, and agency has accelerated, been diversified, and strengthened. Therefore, it has become easier for ship managers (Master, Chief Officer, Chief Engineer, 2nd Engineer, etc.) equipped with specific knowledge to access and transform the knowledge outside their implicit and explicit knowledge. While KM applications for CP are applied without any change (cargo stowage, steps, working hours, etc.) between ship managers and second parties in line with fixed information such as cargo properties and requirements, port properties, and requirements, KM applications may be more effective for NP, since situations such as alternative route determination, speed adjustment, and up-to-date information about the port to be visited entail more information flow and further interpretation, considering factors such as current, traffic density, and security of the region to which the navigation is made, especially for weather conditions for NP. Ship managements can increase their NP by directly supporting the ship (route recommendation, weather, regional and seasonal current information, etc.). Further, NP may have an indirect effect on CP, since there may be problems with the cargo in cases such as the possibility of the ship being exposed to heavy seas during navigation.

The SPSS 22 Hayes [62] Process macro (v3.4) plugin was used to examine whether the BOP has a moderating effect in the relationship between KM applications and ship performance in ship managements. Results of the moderating effect analysis performed using the Bootstrap 5000 sampling technique showed that the BOP lacked a moderating effect in the relationship between the KM and both NP and CP. According to these findings, Hypothesis 3 and Hypothesis 4 were rejected. This finding is congruent with the study by Karaman and Kale [52]. Based on these findings, KM applications in ship managements positively support the NP and CP of ships, regardless of the BOP.

6. Limitations and Suggestions

This study presents some limitations. First, the data were obtained from shipping companies operating in Turkey. Therefore, the findings are limited to this sample. In addition, this study did not consider the differences in the activity fields of shipping companies, i.e., shipping companies operating in the container sector, tanker sector, or dry cargo sector were evaluated together. However, it is known that KM applications and ship performances may differ depending on the activity fields of the shipping companies. Therefore, further research may consider the relationship between the KM and ship performance in shipping firms individually for each sector. Further, different variables can be added to the research model and in-depth studies can be performed to improve this model.

7. Conclusion

To prevent disputes that may occur in maritime transportation, which is at the center of international trade, countries become a party to various agreements and contracts prepared by international organizations on issues such as safety, security, and environmental protection. Commercial ships that do not comply with such agreements and contracts may be inspected by competent authorities and detained when deemed necessary. In this context, there is not a major difference between newly established companies and companies established in earlier years, because all benefit from the same knowledge pool to equip and operate their ships. The main reason for the lack of the moderating effect of the BOP in the relationship between the KM applications and ship performance in ship managements is that all ship managements that want to operate in the maritime sector ensure the safety of life and property in their ships by following processes in line with principles of the international safety management. Therefore, companies have the chance to instantly acquire the knowledge that a company can gain through years of experience. Due to the nature of work done in maritime management and merchant ships, the working period on ships is rather short. Since precious and distinctive knowledge is the implicit knowledge of employees, taking some measures to ensure that these employees stay in the company is important for both ship and firm performances. It is much more substantial for sea transportation that employees are confident, well equipped, and know what they are doing, because even a slight hesitation may cause serious consequences such as environmental pollution and loss of life and property at sea. Thus, business executives can regularly gather their employees and create an environment where they can exchange their knowledge, which also increases the value of human resources and supports the spread of existing knowledge among employees. They can enable their employees to take part in vocational courses and seminars and organize activities in collaboration with educational units of universities, especially for officers at the management level. Further, a training and development department can be established within the management company, so knowledge can be available as a tangible resource within the company and can be applied immediately when requested. This will also increase the prestige of the maritime company for its employees. Moreover, they perform regular and annual work on the effects of the KM applications on the ship and share their findings with the company and the ships under their possession, emphasizing the importance of these applications and encouraging employees in regard to these applications.

Authorship Contributions

Concept design: M. Yorulmaz, Data Collection or Processing: M. Yorulmaz, A. Karabacak, Analysis or Interpretation: M. Yorulmaz, Literature Review: M. Yorulmaz, A. Karabacak, Writing and Reviewing: M. Yorulmaz, A. Karabacak, Editing: M. Yorulmaz.

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Container Ship Investment Analysis Using Picture Fuzzy Present Worth Analysis

Eda Boltürk

İstanbul Technical University, Department of Industrial Engineering, İstanbul, Turkey

Abstract

Investment analysis plays an important role in today's global engineering projects. The present worth analysis is an important investment analysis tool and method in engineering economics. These analyses are performed by humans, and human thoughts are hesitant. Fuzzy sets are frequently used in the literature to eliminate ambiguities in human thoughts. In 1965, Zadeh proposed fuzzy logic as a method of obtaining improved solutions to problems. Since then, fuzzy logic has extended to include hesitant fuzzy sets, q-rung fuzzy sets, Pythagorean fuzzy sets, picture fuzzy sets, type-2 fuzzy sets, Fermatean fuzzy sets, and Spherical fuzzy sets. As can be seen in the literature, present worth analysis has also been extended to its fuzzy versions, such as hesitant present worth analysis and spherical fuzzy present worth analysis. In this study, picture fuzzy present worth analysis is proposed as a new extension of present worth analysis that uses picture fuzzy sets in to create an alternative usage in investment analysis. The introduced method is presented step by step, and a sensitivity analysis is presented with risky parameters in the present worth analysis. Furthermore, the proposed method is compared with spherical fuzzy and classic crisp present worth analysis. The proposed method is used in container ship investment analysis, and future suggestions are provided in the conclusion section.

Keywords

Engineering economics, Picture fuzzy sets, Container ship, Maritime logistics, Investment analysis

1. Introduction

Currently, container ship management is a significant issue because of the increase in trade volume owing to globalization. Through information technology, box cargo transportation has revolutionized the maritime trade industry. The oceans and seas are home to about 50,000 merchant ships registered in 150 countries, carrying approximately 90% of global trade, which encompasses all types of cargo [1]. In 2007, 15 billion tons of cargo were transported by sea to 20,000 ports. For example, Singapore, the heart of Asia and a nodal point connecting 600 major ports, handles 80,000 containers (boxes) and 50 merchant ships per year via 200 shipping companies [1].

Container ship management is a very important subject in maritime logistics because of unforeseen expenditures and the waiting time at ports due to global economic conditions. In addition to these consequences, the coronavirus disease-2019 pandemic appears to have caused investors to be uncertain. Therefore, a container ship investor should conduct an investment analysis before investing in a container ship to avoid high costs. In the literature, these investment analyses have been studied in different forms [2-10].

Vagueness and indefiniteness play a significant role in investment analysis. Indefiniteness can be handled using fuzzy sets, which were proposed by Zadeh [11] in 1965. Since then, fuzzy logic and its extensions, such as fuzzy multisets, Fermatean fuzzy sets, hesitant fuzzy sets, Pythagorean fuzzy sets, picture fuzzy sets, and q-rung orthopair fuzzy sets, have been presented for addressing vagueness. Fuzzy set and its extensions generally use

Address for Correspondence: Eda Boltürk, İstanbul Technical University, Department of Industrial Engineering, İstanbul, Turkey
E-mail: bolturk@itu.edu.tr
ORCID ID: orcid.org/0000-0003-0614-0461

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membership function as a parameter for expressing human thoughts in modeling problems. These extensions are provided in Figure 1.

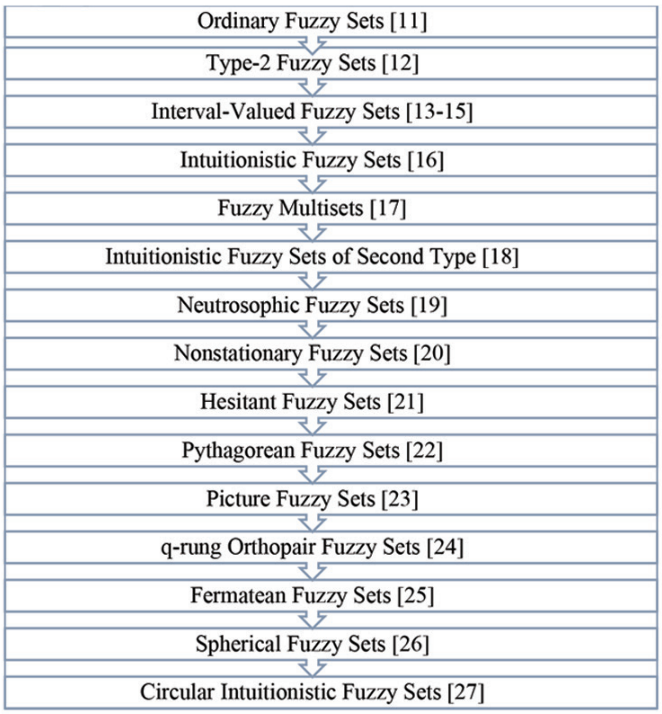

Figure 1. *Milestones of fuzzy set extensions*

Benefit/cost ratio analysis, rate of return analysis, annual cash flow analysis, payback period analysis, and present worth analysis are some of the mathematical methods used for investment analysis under engineering economics subjects. The present worth analysis consists of first cost (FC), interest rate (i), annual benefits (AB), life (n), annual cost (AC), and salvage value (SV) parameters. In the literature, the present worth analysis has been extended to its fuzzy extension forms. Kahraman et al. [28] introduced discounting technique-based financial models. Iliev and Fustik [29] presented fuzzy net present values for assessing hydroelectric projects. Omitaomu et al. [30] presented a present value model for information system projects using triangular fuzzy numbers. Kahraman et al. [31] introduced a fuzzy present worth analysis-based fuzzy model for quantifying manufacturing flexibility with triangular fuzzy numbers. Kahraman and Kaya [32] introduced an investment assessment using fuzzy equivalent annual worth (AW) analysis. Matos and Dimitrovski [33] presented a triangular fuzzy equivalent uniform AW analysis. Kuchta [34] used fuzzy present worth analysis for optimization. Dimitrovski and Matos [35] presented a fuzzy present worth analysis with uncorrelated and correlated cash flow. Shahriari [36] introduced the triangular fuzzy net present value methodology. Kahraman et al. [37] introduced two fuzzy present and AW analyses using intuitionistic and hesitant fuzzy sets with triangular fuzzy numbers. Sarı and Kahraman [38] presented type-2 net present worth analysis. Kahraman et al. [39] presented Pythagorean present worth analysis. Kahraman et al. [40] studied the present worth analysis in wind energy using ordinary fuzzy, type-2 fuzzy, hesitant fuzzy, and intuitionistic fuzzy present worth analyses. Aydin et al. [41] introduced a simplified neutrosophic present worth analysis method and compared it to intuitionistic and ordinary fuzzy present value analyses. Aydin and Kabak [42] developed neutrosophic future and present worth techniques. Sergi and Sari [43] introduced the Fermatean fuzzy capital budgeting method. Çevik Onar et al. [44] presented a spherical engineering economic analysis for evaluating solar energy investment. Bolturk and Seker [45] introduced the spherical fuzzy present worth analysis as a new fuzzy extension of the present worth analysis for analyzing an investment in a summer house in Istanbul.

A literature review was conducted in the Scopus database for fuzzy present worth analysis in order to observe the trend. Figure 2 illustrates the distribution of publications/papers on fuzzy present worth analysis by year, with most of the studies (15%) published in 2018. Figure 3 shows the distribution of document types on fuzzy present worth analysis, with most of the papers (65%) published as articles. Additionally, papers/publications on fuzzy present worth analysis are handled as conference papers, book chapters, conference reviews, and reviews. Figure 4 shows the distribution of papers/publications on fuzzy present worth analysis with respect to their source countries, with Turkey being the leading country. Figure 5 shows the percentage of the top 9 authors who published papers/publications on fuzzy present worth analysis, with Cengiz Kahraman being the leading author.

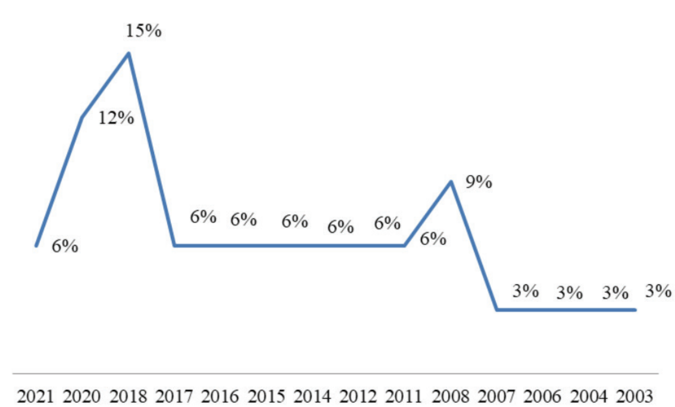

Figure 2. *Distribution of papers/publications on fuzzy present worth analysis with respect to years*

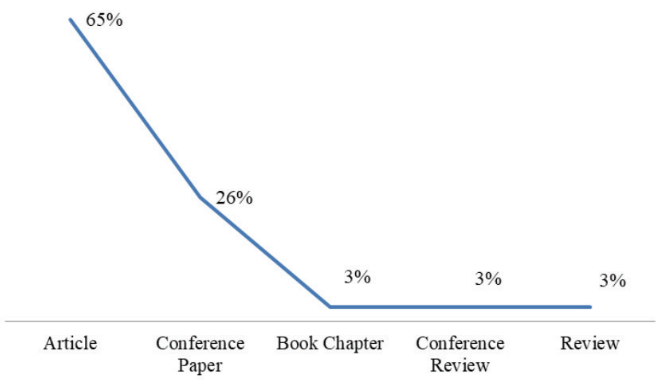

Figure 3. *Distribution of papers/publications on fuzzy present worth analysis with respect to publication types*

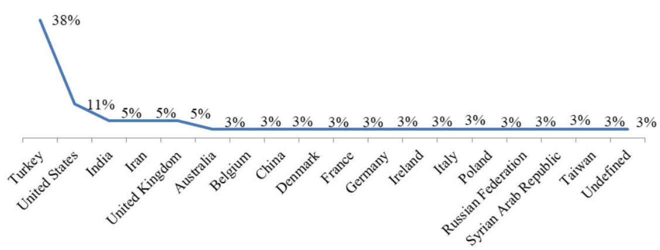

Figure 4. *Distribution of papers/publications on fuzzy present worth analysis with respect to countries*

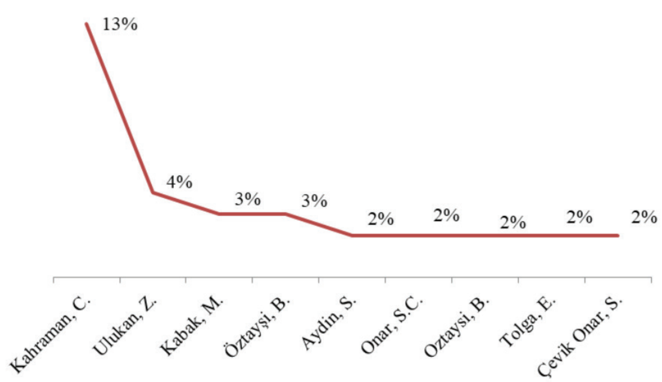

Figure 5. *Percentages of the top 9 authors who published fuzzy present worth analysis papers/publications*

Engineering, computer science, mathematics, economics, econometrics and finance, social sciences, decision sciences, business management and accounting, earth and planetary sciences, environmental science, energy, multidisciplinary, physics, and astronomy are the subject areas covered in papers/publications on the fuzzy present worth analysis. Furthermore, when publications/papers on fuzzy present worth analysis were investigated based on their sources, Advances in Intelligent Systems and Computing, The Engineering Economist, Fuzzy Sets and Systems, IEEE Transactions on Geoscience and Remote Sensing, and Journal of Intelligent and Fuzzy Systems were seen as the first three sources. Kozan [46] combined capital budgeting techniques and queuing simulation models with a cost-benefit analysis to analyze an optimal balance between the opportunity cost of ship waiting time and the cost of expanding the seaport system. Koenig [47] introduced an option-based analysis and developed option-informed naval analyses for real options in ships using force structure analysis. Rehder et al. [48] conducted a techno-economic analysis and a risk analysis for sea transport, and the safety level of the new concept was compared to that of ship types. Marinacci et al. [49] used the cost-benefit analysis to evaluate voltage, power demand, frequency, and power supply parameters on the quay ships in cold-ironing scenarios. Pawlak [50] evaluated the economic benefits and environmental costs of marine vessel fuels from the perspectives of the infrastructure event. In 2015, Santos and Guedes Soares [51] evaluated the economic feasibility of a liquefied natural gas bunkering service in the Atlantic islands and Portuguese coast. Furtado et al. [52] used an input-output analysis to assess the economic and social impacts of local content management in oil and gas and shipbuilding industries in Brazil. Truszczyński and Pezała [53] identified and characterized container terminal congestion to develop a decision-making model in order to reduce the risk of congestion, which has negative economic, social, and environmental consequences. van der Kolk et al. [54] developed a vessel model for the performance of wind-assisted ships that was combined with a routing tool to evaluate the fuel savings available from the installation using a combination of economic analyses. The results of this case study are presented in terms of fuel savings and payback period analysis. Jiang et al. [55] analyzed economic investment, technical standards, management regulations, and other issues that arise during the actual promotion process, as well as conducted research on pure battery-powered ships for the Yangtze River.

To the best of our knowledge, there is no present worth analysis study that is based on picture fuzzy sets in engineering economics. The main goal of this study is to introduce picture fuzzy present worth analysis, a new method for present worth analysis with picture fuzzy sets. In this study, picture fuzzy present worth analysis is a novel proposed method that is used in the shipping industry. This paper is organized as follows: the preliminaries of picture fuzzy sets are presented as definitions and formulas in Section 2, the proposed picture fuzzy present worth analysis is presented step by step in Section 3, an application for calculating the present worth value of a container ship investment is provided in Section 4 to demonstrate the applicability of the proposed method, and future suggestions and obtained results are summarized in Section 5 as a conclusion.

2. Picture Fuzzy Sets

In 2014, Cuong and Kreinovich introduced picture fuzzy sets as a new fuzzy set extension [56]. Picture fuzzy set-based models, which are sufficient in situations where we encounter human ideas, include more types of responses, such as "yes," refusal, "abstain," and "no" [56]. A voting example can be used to illustrate in detail. Human voters can be divided into four groups: those who "vote for," "refuse to vote," "vote against," and are "hesitant" [56]. The following are the definitions of picture fuzzy sets:

Definition 1: A picture fuzzy set on an $\tilde{A}_p$ of the universe of discourse, U, is shown in Equations 1, 2:

$$\tilde{A}_p = \left\{ \left\langle u, (\mu_{\tilde{A}_p}(u), v_{\tilde{A}_p}(u), \pi_{\tilde{A}_p}(u)) \middle| u \in U \right\rangle \right\}, \tag{1}$$

where

$$\mu_{\tilde{A}_p}(u): U \to [0,1],\ v_{\tilde{A}_p}(u): U \to [0,1],\ \pi_{\tilde{A}_p}(u): U \to [0,1],$$

and

$$0 \le \mu_{\tilde{A}_p}(u) + v_{\tilde{A}_p}(u) + \pi_{\tilde{A}_p}(u) \le 1 \qquad \forall u \in U. \tag{2}$$

Thus, for each $\boldsymbol{u}$, numbers $\mu_{\tilde{A}_s}(u)$, $v_{\tilde{A}_s}(u)$, and $\pi_{\tilde{A}_s}(u)$ are the degrees of membership, non-membership, and hesitancy of u to $\tilde{A}_S$, respectively. The formula of refusal degree is provided in Equation 3 for picture fuzzy sets [56].

$$\rho = 1 - \left(\mu_{\tilde{A}_p}(u) + v_{\tilde{A}_p}(u) + \pi_{\tilde{A}_p}(u) \right) \tag{3}$$

Definition 2: The basic operators for single-valued picture fuzzy sets are presented in Equations 4-7 [56].

$$\tilde{A}_p \oplus \tilde{B}_p = \left\{ \mu_{\tilde{A}_p} + \mu_{\tilde{B}_p} - \mu_{\tilde{A}_p}\mu_{\tilde{B}_p}, \pi_{\tilde{A}_p}\pi_{\tilde{B}_p}, v_{\tilde{A}_p}v_{\tilde{B}_p} \right\}, \tag{4}$$

$$\tilde{A}_p \otimes \tilde{B}_p = \left\{ \mu_{\tilde{A}_p}\mu_{\tilde{B}_p}, \pi_{\tilde{A}_p} + \pi_{\tilde{B}_p} - \pi_{\tilde{A}_p}\pi_{\tilde{B}_p}, v_{\tilde{A}_p} + v_{\tilde{B}_p} - v_{\tilde{A}_p}v_{\tilde{B}_p} \right\}, \tag{5}$$

$$\lambda \cdot \tilde{A}_p = \left\{ \left(1 - \left(1 - \mu_{\tilde{A}_p} \right)^{\lambda} \right), \pi_{\tilde{A}_p}^{\lambda}, v_{\tilde{A}_p}^{\lambda} \right\} \ for\ \lambda > 0, \tag{6}$$

$$\tilde{A}_p^{\lambda} = \left\{ \mu_{\tilde{A}_p}^{\lambda}, \left(1 - \left(1 - v_{\tilde{A}_p} \right)^{\lambda} \right), \left(1 - \left(1 - \pi_{\tilde{A}_p} \right)^{\lambda} \right) \right\} \ for\ \lambda > 0. \tag{7}$$

Definition 3: Wei [57] proposed a single-valued picture fuzzy weighted averaging (PFWA) operator for picture fuzzy sets with respect to $w=(w_1, w_2, \ldots, w_n)$; $w_i \in [0,1]$; $\sum_{i=1}^{n} w_i = 1$ is presented in Equation 8;

$$PFWA_w(\tilde{A}_1, \ldots, \tilde{A}_n) = w_1\tilde{A}_1 + w_2\tilde{A}_2 + \ldots + w_n\tilde{A}_n = \left\{ 1 - \prod_{i=1}^{n}(1-\mu_{\tilde{A}_i})^{w_i}, \prod_{i=1}^{n} v_{\tilde{A}_i}^{w_i}, \prod_{i=1}^{n} \pi_{\tilde{A}_i}^{w_i} \right\} \tag{8}$$

Definition 4: [58] Equations 9 and 10 define the score and accuracy functions for sorting picture fuzzy numbers (PFNs), respectively. Equation 9 can also be used to defuzzify PFNs.

$$Score\left(\tilde{A}_p\right) = \frac{1}{2}\left(1 + 2\mu_{\tilde{A}_p} - v_{\tilde{A}_p} - \pi_{\tilde{A}_p}/2 \right), \tag{9}$$

$$Accuracy\left(\tilde{A}_p\right) = \mu_{\tilde{A}_p} + v_{\tilde{A}_p} + \pi_{\tilde{A}_p}. \tag{10}$$

Note that $\tilde{A}_p < \tilde{B}_p$ if and only if

(i) Score $(\tilde{A}_p)$ <Score$(\tilde{B}_p)$ or

(ii) Score $(\tilde{A}_p)$ =Score$(\tilde{B}_p)$ and Accuracy $(\tilde{A}_p)$ <Accuracy$(\tilde{B}_p)$.

3. Proposed Picture Fuzzy Present Worth Method

Picture fuzzy sets are a direct extension of intuitionistic fuzzy sets that can model uncertainty in situations involving more of yes, abstain, and no answer types. The concept of neutrality degree can be observed in situations where we are confronted with human opinions involving more answer types, such as yes, abstain, no, and refusal [59]. Thus, picture fuzzy sets were chosen to extend the present worth analysis method. The difference between picture fuzzy sets and intuitionistic fuzzy sets is the concept of neutrality degree, which is missing from the intuitionistic fuzzy set theory [59].

The FC, SV, AB, AC, i, and n parameters are provided with picture fuzzy membership values and expressed as PFNs in Equations 11-16.

$$\widetilde{FC}_P = \left\{ \begin{array}{c} \langle fc_1, N_1, \ldots, PFN_m \rangle, \langle fc_2, SPN_1, \ldots, PFN_m \rangle, \\ \ldots, \langle fc_k, PFN_1, \ldots, PFN_m \rangle \end{array} \right\}, \tag{11}$$

$$\widetilde{AC}_P = \left\{ \begin{array}{c} \langle ac_1, PFN_1, \ldots, PFN_m \rangle, \langle ac_2, PFN_1, \ldots, PFN_m \rangle, \ldots, \\ \langle ac_k, PFN_1, \ldots, PFN_m \rangle \end{array} \right\}, \tag{12}$$

$$\widetilde{AB}_P = \left\{ \begin{array}{c} \langle ab_1, PFN_1, \ldots, PFN_m \rangle, \langle ab_2, PFN_1, \ldots, PFN_m \rangle, \ldots, \\ \langle ab_k, PFN_1, \ldots, SPN_m \rangle \end{array} \right\}, \tag{13}$$

$$\widetilde{SV}_P = \left\{ \begin{array}{c} \langle sv_1, PFN_1, \ldots, PFN_m \rangle, \langle sv_2, PFN_1, \ldots, PFN_m \rangle, \ldots, \\ \langle sv_k, PFN_1, \ldots, PFN_m \rangle \end{array} \right\}, \tag{14}$$

$$\tilde{i}_P = \left\{ \begin{matrix} \langle i_1, PFN_1, \dots, PFN_m \rangle, \langle i_2, PFN_1, \dots, PFN_m \rangle, \dots, \\ \langle i_k, PFN_1, \dots, PFN_m \rangle \end{matrix} \right\}, \quad (15)$$

$$\tilde{n}_P = \left\{ \begin{matrix} \langle n_1, PFN_1, \dots, PFN_m \rangle, \langle n_2, PFN_1, \dots, PFN_m \rangle, \dots, \\ \langle n_k, PFN_1, \dots, PFN_m \rangle \end{matrix} \right\}, \quad (16)$$

The present worth analysis value is calculated using Equation 17 as follows:

$$\widetilde{PW}_P = -\widetilde{FC}_P - \widetilde{AC}_P \left[\frac{(1+\tilde{i}_P)^{\tilde{n}_P}-1}{\tilde{i}_P (1+\tilde{i}_P)^{\tilde{n}_P}} \right] + \widetilde{AB}_P \left[\frac{(1+\tilde{i}_P)^{\tilde{n}_P}-1}{\tilde{i}_P (1+\tilde{i}_P)^{\tilde{n}_P}} \right] + \widetilde{SV}_P (1+\tilde{i}_P)^{-\tilde{n}_P}, \quad (17)$$

where $\widetilde{PW}_P$ is picture fuzzy present worth, $\widetilde{FC}_P$ is picture fuzzy FC, $\widetilde{AB}_P$ is picture fuzzy AB, $\widetilde{AC}_P$ is picture fuzzy AC, $\tilde{i}_P$ is picture fuzzy i, $\widetilde{SV}_P$ is picture fuzzy SV, and $\tilde{n}_P$ is picture fuzzy n.

Picture fuzzy set aggregation was executed using Equation 8. After aggregation, parameter values can be calculated by multiplying the defuzzified parameter values with membership functions. The score function and defuzzification of memberships are used to obtain crisp values for each parameter. Figure 6 shows the steps for the proposed picture fuzzy present worth analysis method as a flowchart.

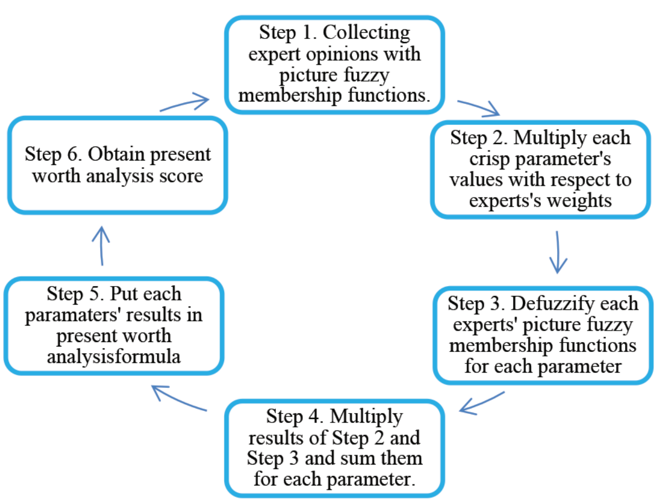

Figure 6. *Flowchart of the proposed picture fuzzy present worth analysis method*

4. Application: Container Ship Investment Analysis

An illustrative example is presented in this section. In this study, a generated unreal container ship, m/v EdBmU, was considered. The problem was constructed based on the information provided by five experts from the maritime logistics field. These experts are named E1, E2, E3, E4, and E5, and they each present their weighted opinions. The parameter values are provided approximately. Each expert was weighted based on their personal experiences, and E3 had the most weight because he has worked in the maritime logistics sector for a long time. The experts' weights are 0.1, 0.2, 0.3, 0.15, and 0.25, respectively. Table 1 presents the experts' thoughts on EdBmU as values. Each parameter value in Table 1 consists of an unreal data set that converges to a real data set. Each expert assigned picture fuzzy set memberships independently, with picture fuzzy membership for each parameter. The limitation of this study is that the summation membership, non-membership, and hesitancy of picture fuzzy membership is between 0 and 1.

AC includes annual maintenance cost, fuel, management cost, labor cost, and insurance cost, while AB includes trade profit.

The following is a list of detailed data regarding the present worth analysis of the container ship in this application:

- **Ship Type Characteristics:** A geared cargo-handling container ship.
- **Capital Expenditures:** The FC consists of purchasing cost, loan expenditures, credit installment, insurance cost, and container equipment.
- **Operational Expenditure:** The operational expenditures (AC) of the container ship are crew expenditures, victualing, maintenance and repair costs, spares, stores, lubricant, surveys and audits, dry dock costs, communication costs, administration costs, brokerage, and insurance. The depreciation costs, such as scrap metal prices and lightship displacement, are handled in this item.
- **Revenue:** The revenue is handled using the AB and SV parameters. The revenue of this container ship is derived from annual freight and SV at the end of its service life.

Table 2 shows the weighted values and defuzzified membership functions. Equation (9) is used to defuzzify these membership functions. The defuzzified membership function for E1's thoughts on FC is calculated as follows (Equation 18):

$$FC_{E1} = \frac{1}{2} \times \left(1 + 2 \times 0.5 - 0.4 - \frac{0.1}{2}\right) = 0.775, \quad (18)$$

Table 3 shows the score values calculated using Table 2 values and Equation 8.

The total defuzzified score for;

$$n = 3 \times 0.425 + 6.4 \times 1.100 + 9.9 \times 1.025 + 4.65 \times 0.475 + 8.75 \times 0.875 = 28.328. \quad (19)$$

To obtain the present worth analysis values, the score values are entered into the present worth formula. For the m/v EdBmU container ship, the score value is \$896,887.85.

$$PWA_{EdBmU} = -1448125 + 1032312.5 \times \left(\frac{(1+0.44)^{28.328}-1}{0.44\times(1+0.44)^{28.328}}\right) - 620.313 \times \left(\frac{(1+0.44)^{28.328}-1}{0.44\times(1+0.44)^{28.328}}\right) + 44217.50 \times (1+0.44)^{-28.328}, \quad (20)$$

$$PWA_{EdBmU} = \$896{,}887.85.$$

5. Sensitivity Analysis

Sensitivity analysis is based on the total defuzzified scores, which are shown in Table 2. The five experts mutually agreed that the most critical parameters in the present worth analysis are *FC* and *AB* because of unforeseen insurance costs and currency arbitrage. The AW formula is provided in Equation 21, and the sensitivity analysis parameters are obtained using Equation 21.

$$AW = -FC(A/P,\ i\%,\ n)\ (1+x) + AB(1+y) - AC + SV(A/F,\ i\%,\ n), \quad (21)$$

$$AW = -1448125\ (A/P,\ 4{,}4\%,\ 28.32)\ (1+x) + 103312.5\ (1+y) - 620.313 + 44217.5(A/F,\ 4{,}4\%,\ 28.32), \quad (22)$$

$$AW = -1448125 \times \left(\frac{(1+0.044)^{28.32}-1)}{0.044\times(1+0.044)^{28.32}}\right)^{-1}(1+x) + 103312.5\ (1+y) - 620.313 + 44217.5 \times \left(\frac{(1+0.044)^{28.32}-1}{0.044}\right)^{-1}, \quad (23)$$

Table 1. *The values for the m/v EdBmU container ship*

Parameters	Experts	Experts' weights	Picture fuzzy memberships (μ,ϑ,π)	Parameter values ($)	Picture fuzzy values
First cost	E1	0.1	(0.5,0.4,0.1)	1,500,000	⟨1,500,000; 0.5,0.4,0.1⟩
	E2	0.2	(0.6,0.1,0.1)	2,200,000	⟨2,200,000; 0.6,0.1,0.1⟩
	E3	0.3	(0.3,0.3,0.4)	1,700,000	⟨1,700,000; 0.3,0.3,0.4⟩
	E4	0.15	(0.2,0.3,0.5)	1,800,000	⟨1,800,000; 0.2,0.3,0.5⟩
	E5	0.25	(0.6,0.3,0.1)	2,100,000	⟨2,100,000; 0.6,0.3,0.1⟩
Annual benefit	E1	0.1	(0.7,0.1,0.2)	1,500,000	⟨1,500,000; 0.7,0.1,0.2⟩
	E2	0.2	(0.6,0.1,0.1)	1,750,000	⟨1,750,000; 0.6,0.1,0.1⟩
	E3	0.3	(0.1,0.2,0.3)	1,800,000	⟨1,800,000; 0.1,0.2,0.3⟩
	E4	0.15	(0.1,0.3,0.3)	1,750,000	⟨1,750,000; 0.1,0.3,0.3⟩
	E5	0.25	(0.2,0.3,0.5)	1,700,000	⟨1,700,000; 0.2,0.3,0.5⟩
Annual cost	E1	0.1	(0.3,0.1,0.2)	800	⟨800; 0.3,0.1,0.2⟩
	E2	0.2	(0.2,0.3,0.5)	900	⟨900; 0.2,0.3,0.5⟩
	E3	0.3	(0.6,0.1,0.2)	750	⟨750; 0.6,0.1,0.2⟩
	E4	0.15	(0.4,0.5,0.1)	650	⟨650; 0.4,0.5,0.1⟩
	E5	0.25	(0.6,0.2,0.2)	850	⟨850; 0.6,0.2,0.2⟩
Salvage value	E1	0.1	(0.8,0.1,0.1)	65,000	⟨65,000; 0.8,0.1,0.1⟩
	E2	0.2	(0.2,0.3,0.4)	60,000	⟨60,000; 0.2,0.3,0.4⟩
	E3	0.3	(0.6,0.1,0.1)	55,000	⟨55,000; 0.6,0.1,0.1⟩
	E4	0.15	(0.5,0.3,0.2)	61,500	⟨61,500; 0.5,0.3,0.2⟩
	E5	0.25	(0.1,0.3,0.3)	70,000	⟨70,000; 0.1,0.3,0.3⟩
Interest rate (i)	E1	0.1	(0.1,0.1,0.3)	0.8	⟨0.8; 0.1,0.1,0.3⟩
	E2	0.2	(0.6,0.1,0.1)	0.9	⟨0.9; 0.6,0.1,0.1⟩
	E3	0.3	(0.2,0.3,0.5)	0.55	⟨0.55; 0.2,0.3,0.5⟩
	E4	0.15	(0.1,0.1,0.3)	0.8	⟨0.8; 0.1,0.1,0.3⟩
	E5	0.25	(0.2,0.3,0.5)	0.85	⟨0.85; 0.2,0.3,0.5⟩
Life (n)	E1	0.1	(0.2,0.3,0.5)	30	⟨30; 0.2,0.3,0.5⟩
	E2	0.2	(0.7,0.1,0.2)	32	⟨32; 0.7,0.1,0.2⟩
	E3	0.3	(0.6,0.1,0.1)	33	⟨33; 0.6,0.1,0.1⟩
	E4	0.15	(0.1,0.1,0.3)	31	⟨31; 0.1,0.1,0.3⟩
	E5	0.25	(0.5,0.2,0.1)	35	⟨35,0.5,0.2,0.1⟩

$$= -63719.59 - 63719.59x + 103312.5 + 103312.5y - 620.313 + 815.65, \quad (24)$$

$$= -63719.59x + 103312.5y + 970028.87, \quad (25)$$

$$(x,y) = (15.22;0), \quad (26)$$

$$(x,y) = (0;-0.94), \quad (27)$$

***Table 2.** The values for the m/v EdBmU container ship*

Parameters	Experts	Weighted values	Defuzzified membership functions
First cost	E1	150,000	0.775
	E2	440,000	1.025
	E3	510,000	0.550
	E4	270,000	0.425
	E5	525,000	0.925
Annual benefit	E1	150,000	1.100
	E2	350,000	1.025
	E3	540,000	0.425
	E4	262,500	0.375
	E5	425,000	0.425
Annual cost	E1	80	0.700
	E2	180	0.425
	E3	225	1.000
	E4	97.5	0.625
	E5	212.5	0.950
Salvage value	E1	6,500	1.225
	E2	12,000	0.450
	E3	16,500	1.025
	E4	9,225	0.800
	E5	17,500	0.375
Interest rate	E1	0.08	0.475
	E2	0.18	1.025
	E3	0.17	0.425
	E4	0.12	0.475
	E5	0.21	0.425
Life	E1	3.00	0.425
	E2	6.40	1.100
	E3	9.90	1.025
	E4	4.65	0.475
	E5	8.75	0.875

***Table 3.** The scores of the present worth analysis parameters*

Parameters	Weighted values	Defuzzified total scores
First cost	1,895,000	1,448,125
Annual benefit	1,727,500	1,032,312.50
Annual cost	795	620.313
Salvage value	61,725	44,217.500
Interest rate	0.76	0.440
Life	32.70	28.328

Figure 7 shows that the container ship investor incurs no risk if the *FC* and *AB* values are greater than the square of ±51.43%. This means that the container will remain unaffected by various changes in FC and AB up to 51.43% in any direction.

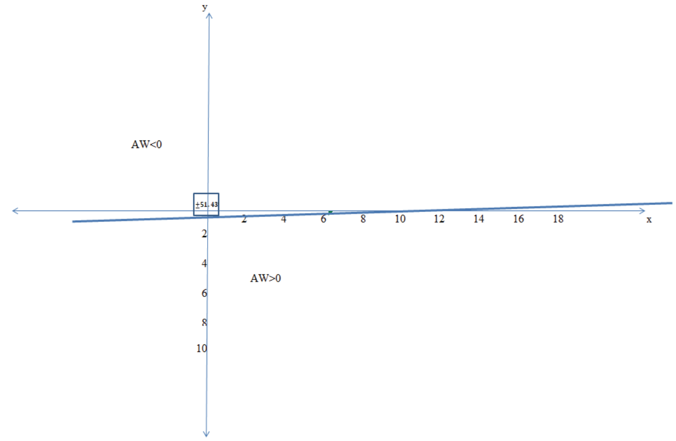

***Figure 7.** Sensitivity analysis of the FC and AB parameters*

FC: First cost, AB: Annual benefits

6. Comparison Analysis with Spherical Fuzzy Present Worth Analysis

In this study, the proposed method was compared with the spherical fuzzy present worth analysis method, which was introduced by Bolturk and Seker [45], and all membership values were taken as spherical fuzzy numbers, as shown in Table 1. Score values were entered into the present worth formula to obtain the spherical fuzzy present worth analysis values, and the value for m/v EdBmU container ship is $471,022.809. In addition, all parameters were aggregated using classic crisp arithmetic operations and the value for the m/v EdBmU container ship is $424,475.86 (Equations 28 and 29 as below).

$$Spherical\_PWA_{EdBmU} = -1968268.03 + 1681001.73 \times \left(\frac{(1+0.70)^{32.77}-1}{0.70\times(1+0.70)^{32.77}}\right) - 787.26 \times \left(\frac{(1+0.70)^{32.77}-1}{0.70\times(1+0.70)^{32.77}}\right) + 60358.13 \times (1+0.70)^{-32.77}, \quad (28)$$

$$Spherical\_PWA_{EdBmU} = \$471{,}022.81$$

$$Classic\ crisp\_PWA_{EdBmU} = -1895000 + 1727500 \times \left(\frac{(1+0.76)^{32.7}-1}{0.76\times(1+0.76)^{32.7}}\right) - 795 \times \left(\frac{(1+0.76)^{32.7}-1}{0.76\times(1+0.76)^{32.7}}\right) + 61725 \times (1+0.76)^{-32.7}, \quad (29)$$

$$Classic\ Crisp\_PWA_{EdBmU} = \$424{,}475.86$$

7. Conclusion and Future Works

Herein, a new fuzzy engineering economics analysis method called the picture fuzzy present worth analysis method is proposed, with an application for container ship investment analysis. Picture fuzzy set [57] is a recently used fuzzy set extension that uses positive membership, degree of membership, neutral membership, and degree of negative membership functions to handle vagueness. Human thoughts can be shaped with picture fuzzy sets when they consist of "yes," refusal, "abstain," and "no" answers [57].

Present worth analysis with fuzzy sets is widely used in investment analysis to better model the problem. In this study, the advantage of shaping human thoughts into four terms is used for investment analysis, and picture fuzzy sets were used in the present worth analysis. The proposed method was applied in an illustrative application. A container ship investment analysis was taken as a problem, and the parameter values of the present worth analysis were determined by five experts who work in the maritime logistics field. The picture fuzzy set parameters could model each expert's thoughts with degrees of positive membership, negative membership, and refusal membership. The experts' opinions were defuzzified based on picture fuzzy set definitions, and the defuzzified values were used in calculating the present worth. The present worth value in our application is $896,887.85. Furthermore, the proposed method is compared with the spherical fuzzy present worth analysis method and classic crisp methods to demonstrate the applicability of the proposed method.

In future research, a comparison of the proposed picture fuzzy present worth analysis and other present worth analysis fuzzy extensions can be explored using different applications to understand the power of fuzzy set extensions. Additionally, new fuzzy set extensions, such as q-rung fuzzy sets, can be used in present worth analysis methods, and experts' opinions can be used to compare extended fuzzy present worth analysis methods with possible q-rung fuzzy orthopair present woth analysis. However, a holistic approach that considers the ship as a whole and includes the machinery can be examined in more detail.

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Developing a Scale to Measure the Institutionalization Level of Maritime Family Businesses

Barış Demir[1], Leyla Tavacıoğlu[2]

[1]Zonguldak Bülent Ecevit University, Karadeniz Ereğli Vocational High School, Department of Maritime and Port Management, Zonguldak, Turkey
[2]İstanbul Technical University Maritime Faculty, İstanbul, Turkey

Abstract

Institutionalization is an important strategy that can help family businesses survive in developing market conditions. Measuring the institutionalization level of companies can improve the understanding of current corporate governance statuses and reveal institutionalization problems. Here, we developed a scale to measure the institutionalization level of maritime family businesses. Data obtained by questionnaires from 193 office employees in 177 Turkish family-owned ship management companies were analyzed by exploratory factor analysis and confirmatory factor analysis via structural equation modeling in the SPSS 23.0 and AMOS 23.0 statistical programs as quantitative methods. Following rigorous scale development procedures, a scale was developed consisting of 14 items and three dimensions. The three dimensions are effective organizational structure, internal audit, and transfer of authority. Based on the results, the scale was determined to be reliable and valid. Finally, the implications of the study were discussed and suggestions were given for additional studies.

Keywords

Maritime family businesses, Institutionalization level, Corporate governance, Ship management, Company generation

1. Introduction

Family businesses are important drivers of the world economy's Gross National Product (GDP). They constitute 80-98% businesses around the world, make up around 70-75% annual global GDP, and account for 50-80% jobs [1]. Traditionally, family-owned firms make up the largest proportion of maritime businesses. According to Alphaliners' Top 100 indicators [2], family firms are among the most effective shipping companies and play an important role in the maritime sector.

Institutionalization studies of family businesses have been a popular topic over the last two decades. The reason is that the researchers think institutionalization is necessary for the sustainability of family businesses due to intense competition conditions in the market [3,4]. Moreover, most family businesses lose their existence before reaching the second generation of company [5,6].

Institutionalization is defined either as the standardization of repetitive actions and habits within communities or the set of rules that must be followed [7]. Institutionalization is the process of "having rules, standards, and procedures independent of individuals, establishing systems that follow changing environmental conditions, establishing an organizational structure suitable for developments, making its own communication and business methods into a culture and thus transforming it into a distinctive identity from other businesses" [8]. This term is also used for corporate governance or corporate management in the literature.

In this study, we developed a scale to measure the institutionalization levels of maritime family businesses. Institutionalization studies in the maritime field typically measure the attitudes of business owners, shareholders, or chief executive officers (CEOs) [9,10]. However, the reflection of corporate governance practices is on the

Address for Correspondence: Barış Demir, Zonguldak Bülent Ecevit University, Karadeniz Ereğli Vocational High School, Department of Maritime and Port Management, Zonguldak, Turkey
E-mail: baris.demir@beun.edu.tr
ORCID ID: orcid.org/0000-0003-1975-1077

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employees [11]; thus, we instead measured the attitudes of employees. Using this strategy, the institutionalization level of companies was better measured. Determining the institutionalization levels of businesses helps to understand their current corporate status [8]. The scale developed in this study is aimed to determine institutionalization levels of maritime family businesses and to reveal deficiencies in institutionalization. In addition, determining the institutionalization level of businesses can elucidate relationships between institutionalization and managerial factors, such as, human resources, leadership, strategic management, financial performance, and organizational culture. These relationships have been examined for other sectors [12-16]; however, studies about the maritime sector are limited.

The maritime industry has a unique structure; thus, the institutionalization of this industry should be evaluated within the scope of its own structure. In this study, we define the following three factors for the institutionalization level of maritime companies: effective organizational structure, transfer of authority, and internal audit.

Literature and expert opinions (EOs) were used to create the items in the questionnaire. Exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) were used as quantitative methods to analyze questionnaire data obtained from family-owned ship management companies registered with the Turkish Chamber of Shipping. The final scale consisted of 14 items and 3 dimensions. The developed scale was determined to be reliable and valid, and the impact of this study on the literature was discussed.

2. Background

The institutionalization of organizations is an approach that flourished with the emergence of institutional theory, which focuses on the development, legitimacy, and sustainability of organizations by using sociology, politics, and economics [17]. The main themes of institutional theory for organizations are formation of institutions, relationships between social characteristics and institutionalization, and the structure, function, and institutionalization of organizations.

Although the history of institutionalization dates back to the 19th century with the emergence of sociology, its effects on organizations were reflected only in the literature in the 20th century. This theory, founded by Selznick [18] after 1940, progressed into two different frameworks after 1970, the old and the new institutionalization approach. According to Selznick [18], the old institutionalization approach is related to deviations from personal interests, power, influence, competing values, and goals, and the new institutionalization approach is dependent on rules and laws, isomorphism, definitions, schemas, and routines.

Scott [19] defines institutionalization as a system of consistent and harmonious activities that emerge as a result of an enterprise's interaction with its environment, and the process of making the rules, policies, procedures, and practices that emerge as a result of this system. Accordingly, Kimberly [20], defines institutionalization as the effort to establish a mechanism that foresees the change of a new norm, value, and structure. This mechanism takes into account social relations by creating a structure suitable for the norms and values of organizations in order to keep up with the change. The common view in these definitions is that institutionalization is a process for businesses to build a certain structure to keep up with the environment and change.

Institutionalization begins with the establishment and development of an enterprise [20]. Various institutionalization dimensions have been used in the literature to measure the structural changes and institutionalization level of a company since its establishment. Such institutionalization criteria or dimensions include formalization, strategic planning, professionalization, transfer of authority, participation in management, decision-making style, existence of an effective communication system, and internal audit [21,22].

Studies on the institutionalization of both family-owned and non-family-owned businesses have been reported. Leaptrott [23] emphasized the importance of institutionalization in family businesses and argued that institutional theory can explain the relationships between family, business, and ownership within family businesses, after taking into account other external factors. Family businesses are defined as companies established for the purpose of making a living for the family and for profit, having blood ties between the founders and some of their managers, with at least two generations working in the business, and for transferring knowledge and skills from the family to the business to create a culture [24].

The main problems in family businesses involve adapting to changing market conditions and sustainability [3,4]. Researchers have examined relationships between institutionalization and managerial factors by using institutionalization dimensions that measure the level of institutionalization in family businesses operating in various fields. For example, Alpay et al. [25] conducted a study with 436 respondents from 132 family businesses and examined the relationship between institutionalization and firm performance. They determined the following three different aspects of institutionalization: transparency (internal audit), objectivity or justice, and formalization or professionalism. They emphasized that transparency had a strong direct effect on firm performance. Additionally, objectivity or fairness in employee relations exerted a positive influence on qualitative performance measures. Furthermore, it was determined that formalization and professionalism cannot be achieved without transparency. Another study by Çavuş and Demir [26], with 244 managers of family firms, pointed out the relationship between institutionalization and corporate entrepreneurship. This study used the institutionalization dimensions of formalization, autonomy, professionalization, transparency, and consistency, and emphasized the significant relationship between institutionalization and corporate entrepreneurship.

Family businesses play an important role in the maritime industry, especially in ship management [10]. The most effective ship management companies are typically established as family companies and subsequently institutionalized [2]. However, companies that cannot be institutionalized, particularly the Turkish firms that are the subject of this study, cannot ensure their sustainability [27]. Ship management companies that operate as family businesses in Turkey generally employ a management approach that is passed from father to son [28]. A child's lack of necessary skills or knowledge, or their preference to not continue in the maritime sector, can negatively affect the continuity of the business. In cases where there are multiple children per family, ship-sharing and company separations after the death of the head of the family can cause the company to divide into smaller parts and disappear over time, rather than growing and developing [28].

Studies on institutionalization in maritime family businesses are limited. These studies, which are mostly focused on data obtained from the financial performance of the company, generally deal with either corporate governance and the impact of having a CEO on the board of directors or shareholder relationships on business performance.

Giannakopoulou et al. [10] pointed out that corporate governance is beneficial for maritime managers and shareholders, especially in family-owned maritime businesses.

The only study on the institutional levels in maritime businesses was performed by Turhaner and Nas [9]. In this study, which was conducted on 64 Turkish maritime family businesses, data from the opinions of shipowners were used. In this qualitative study, they specified the level of institutionalization as pre, semi, or full institutionalization by using institutionalization dimensions.

In contrast to the literature, our study is quantitative and based on institutional theory for employees in ship management companies. Employees are directly affected by institutionalization [11]; thus, it is beneficial to get opinions from employees and to measure institutionalization practices rather than the opinions of shipowners. This method circumvents involuntary and prejudiced attitudes that may occur when shipowners evaluate their own institutions.

In this study, scale dimensions developed for maritime family businesses are defined as the effective organizational structure, transfer of authority, and internal audit, according to the institutionalization literature and EOs.

2.1. Effective Organizational Structure

The structure of an organization is closely related to the content of its activities and culture. It is important to create rules that are based on the culture of the organization and that represent the relationship between jobs, people, groups, and processes to achieve goals [29]. In order for these relations and rules to be regulated, the organizational structure should include a formalized, professional, centralized, and fair management approach [30-32]. Formalization implies that an organization's actions are managed by specific and written rules, standards, and procedures [33,34]. A formal structure controls and coordinates a business's actions. Thus, employees are provided with knowledge and the business is provided with stability. Since this structure contains a rational management relationship set, a formal structure reflects institutionalized values [35]. Professionalization implies that the work and transactions in an organization are performed by experts. In professionalization, the balance of duty, authority, and responsibility in a business is determined on the basis of expertise [36]. An alternative definition by Apaydın [35] suggests that professionalization involves employing professionals in business management, establishing an organizational culture in a way that supports the work of professionals, establishing relationships with professionals and sectoral institutions in the sector where the business is located, and is an indicator of institutionalization. A centralized and fair organizational structure accomplished by establishing a hierarchical structure helps to manage relations and jobs. There are strong relationships between procedural, distributive, and interactional justice and job satisfaction under conditions of high centralization [37].

Based on these definitions, the establishment of an effective organizational structure for the institutionalization of family businesses depends on the following stages: determining the system and principles in the organizational structure, standardizing the work done, assigning powers and responsibilities to non-family employees according to success, the existence of a fair system in the organization, the existence of a unique identity, and the system of selection and placement according to the requirements. In addition, measuring how this organizational structure is reflected on employees enables the effectiveness of current practices to be evaluated. Therefore, the first dimension in this study was determined to be an effective organizational structure.

2.2. Transfer of Authority

A major problem in family businesses is that authority cannot be transferred [38]. Authority is a combination of influencing and directing the behavior of others, which affects the organizational performance of businesses, as it is an important tool in building employee motivation and relationships [39]. However, authority does not only involve granting a status within a business, but also includes taking initiative. Sometimes authority must be transferred according to the needs of an organization and at critical times. Wells [40] defines authority as a managerial transfer of one or more duties or responsibilities to subordinates. Another definition according to Aşkun [41] is the transfer of authority from one manager or organizational unit to another to fulfill certain tasks. McClelland et al. [42] explained the transfer of authority as the reason for success or failure, and reported that employees will accept empowerment if they feel important and gain status in an organization. Thus, these motives should be evaluated with a reward and punishment system.

An organizational structure cannot be completed without the determination of a necessary structure, provision of appropriate physical equipment, and appointment of expert personnel to each department [7]. In order to ensure effective work from all employees, an organizational structure should be connected both horizontally and vertically with authority bonds [43]. The transfer of authority enables employees to take initiative and carry out work more effectively. Thus, employees can better adopt a vision and mission in line with the goals of the organization, and develop a sense of belonging and ownership. This transfer creates motivation for employees, and is therefore one of the important dynamics of orientation [44]. In this context, the transfer of authority was determined as the second indicator of institutionalization.

2.3. Internal Audit

Corporate governance sustains businesses by ensuring the efficient use of business resources together with internal audit processes [45]. According to The Institute of Internal Auditors [46], "Internal auditing is an independent, objective assurance and consulting activity designed to add value and improve an organization's operations. It helps an organization accomplish its objectives by bringing a systematic, disciplined approach to evaluate and improve the effectiveness of risk management, control, and governance processes." Thus, an internal audit is based on the management policies and plans of an organization's activities with the purpose of measuring compliance with programs and laws to evaluate proper function. Karacalar [47] concluded that the establishment of an effective internal audit system within the framework of corporate governance ensured that financial statements, activities, information systems, contracts, compliance, and environmental audits were carried out in the most effective and ethical way.

Audits in maritime businesses are carried out in accordance with international regulations. These audits are for the safety of the environment, people, cargo, and ships at sea, and have been standardized using the International Safety Management Code (ISM). The ISM code advises companies to take precautions against all identified risks, to continuously improve the skills of personnel in the ISM code, and to create policies regarding safety of the environment [48]. According to the ISM code, flag states inspect businesses and their ships with external audits. In addition, ships are inspected by port states in international waters. Thus, ships or companies can be faced with sanctions if non-conformities are found from external audits. These sanctions adversely affect the operational and financial performance of businesses. As a precaution against sanctions, businesses must effectively carry out internal audits. A designated person ashore (DPA) is responsible for these audits. In this study, items involving minute details were prepared together with EOs, including DPAs, to test the structures that make up maritime internal audits.

3. Methodology

In this study, EFA and CFA were used as scale development methods. CFA was applied using structural equation modeling (SEM).

3.1. Scale Development

According to Schwab [49], scale development consists of the following three stages: creating a question pool, structuring the scale, and evaluating the scale. Chen et al. [50] used the scale development steps of item generation and questionnaire design, data collection and purification of measures, and the assessment and verification of the structure of the scale. In this study, scale development was carried out in line with the above assessments and consisted of item generation and questionnaire design and the structuring and assessment of the scale. A pilot study was also applied to test the understanding and reliability of the scale during the item generation and questionnaire design stage.

Data was obtained from 247 family-owned ship management companies registered with the Turkish Chamber of Shipping. A questionnaire made by Google forms was sent to these companies *via* e-mail, and their employees were asked to answer them. The questionnaire period was from October 2020 to February 2021. From the 247 family-owned companies, 193 office employees working in 177 companies responded to the questionnaire. Of the 177 companies, 154 were in İstanbul, 11 were in Kocaeli, 8 were in İzmir, 3 were in Mersin, and 1 was in the Trabzon province. All companies had at least 1 ship of 1000 gross tonnage and above operating in international waters.

According to Muthén and Muthén [51], a sample size of N=150 is generally acceptable for SEM. Thus, our sample size of 193 participants was adequate. The developed scale consists of 24 items, 6 of which are demographic characteristics and 18 are institutionalization levels. After EFA analysis, a final institutionalization level questionnaire was determined with 14 items. In order to acquire organizational culture data, participants working in the business for at least 1 year were sought out.

3.1.1. Item Generation and Questionnaire Design

Items in the scale were generated in the following two ways: EOs and institutionalization literature. For EO, assistance was received through face-to-face interviews from four academics and three DPAs with 10 or more years of working experience. Since the original language of this study was Turkish, a Turkish linguist assisted with the accuracy of the scale. Information about the experts is shown in Table 1.

Items that made up the internal audit factor were mostly shaped by EO, and items that made up the effective organizational structure and transfer of authority factors were adapted from the literature [7,52,53].

Additionally, experts were consulted to verify if items in the scale were within the scope of maritime businesses. All items and their sources are shown in Table 2.

The measurements of institutionalization level were conducted using a five-point Likert-type scale (1: Completely disagree, 2: Disagree, 3: Neither agree nor disagree, 4: Agree, and 5: Strongly agree).

After approval from experts, we proceeded with the pilot study. A scale consisting of 18 items was tested by the pilot study. To validate the understanding and reliability of the items in the scale, 60 participants from 35 family companies in İstanbul, who fit the criteria of the study, were invited to answer the questionnaire *via* Google forms. The questionnaire was sent *via* e-mail in August 2020 and 43 participants responded. The participants were asked if the items reflected the purpose of the study and whether they were understandable. Based on the pilot study, it was determined that the scale items properly reflected the purpose of the study and were understood by the participants.

To test the reliability of the scale, reliability analysis was performed *via* the SPSS 23.0 statistical program. The internal consistency level of the items that make up a scale reflects the reliability of that scale [54]. Cronbach's alpha coefficient is the typical method used for internal consistency, especially in Likert-type scales [54]. This coefficient should typically be greater than 0.70 [55]. The Cronbach alpha value of this pilot study was determined to be 0.92 (Table 3).

The item-reliability performance of the scale was also examined (Table 4). According to Brzoska and Razum [56], a corrected item-total correlation should be at least 0.3. Table 4 shows that the corrected item-total correlations are at an acceptable range (0.31-0.79). The column titled "Cronbach's Alpha Coefficient (Item Deleted)" reports the rate of change in Cronbach's alpha coefficient, if any item is deleted. This value recalculates the Cronbach alpha value for each removed variable. Thus, an increase in scale reliability can be determined based on removing specific variables.

Table 1. *Expert descriptions*

Expert	Employment	Expertise
Professor	Maritime faculty	Efficiency in maritime businesses/organizational and cognitive psychology
Ass. Prof.	Maritime faculty	Maritime business management/corporate management
Ass. Prof.	Maritime faculty	Maritime business management
Ass. Prof.	Maritime faculty	Maritime engineering/ISM code
Ass. Prof. (Linguist)	Faculty of education	Turkish language and literature
DPA	Family-owned ship management company	ISM code
DPA	Non-family-owned ship management company	ISM code
DPA	Corporate ship management company	ISM code
DPA: Designated person ashore, ISM: International Safety Management Code		

Table 2. *Potential indictors of the institutionalization level of maritime family businesses*

Item Number	Item Description	Relevant Sources
A1	In our company, the final decisions are always made by the ship owner.	(EO)
A2	The mission and vision of our company are known by all employees.	[53,7]
A3	The duties, authorities, and responsibilities of the employees in our company are written in detail.	[52]
A4	Our company's seafarers and office employees are recruited by experts.	(EO)
A5	Our company has a fair promotion policy for all employees.	[53]
A6	Employees of our company can easily communicate with each other and with their superiors.	[7]
A7	A fair wage policy is applied for all employees, whether they are family members or not in our company.	[52]
A8	The resignation of one of the company employees does not affect the work flow of our company.	(EO)
A9	Employees in our company can transfer their authority and responsibilities to other employees, if necessary.	(EO), [52]
A10	Employees of our company know whom to transfer their authority and responsibilities, if necessary.	[52]
A11	Employees of our company can take initiative without asking their superiors.	[52]
A12	DPAs are also assigned for jobs other than those defined by the ISM code.	(EO)
A13	Our company has a reward and punishment system for employees.	[52,53]
A14	Internal audits in our company are carried out effectively.	(EO)
A15	The effectiveness of the ISM code is measured on an annual basis in our company.	(EO)
A16	Our seafarers have sufficient knowledge about the function and requirements of the ISM code.	(EO)
A17	Any non-conformity that arises during internal audits conducted in accordance with the requirements of the ISM code in our company is not repeated on our ships.	(EO)
A18	Corrective actions of found non-conformities are carried out as soon as possible regardless of present market conditions.	(EO)
ISM: International Safety Management Code, EO: Expert opinion		

Table 3. *Reliability analysis of the pilot study*

Cronbach's Alpha Coefficient	Mean	Variance	N (Items)	N (Participants)
0.92	58.97	191.62	18	43

Table 4. *Item-total statistics for the pilot study*

Items	Scale Mean (Item Deleted)	Scale Variance if (Item Deleted)	Corrected Item Total Correlation	Cronbach's Alpha Coefficient (Item Deleted)
A1	57.09	198.56	0.43	0.919
A2	55.55	189.91	0.76	0.912
A3	55.69	188.12	0.62	0.915
A4	55.46	186.54	0.70	0.913
A5	56.00	182.90	0.77	0.910
A6	54.90	190.56	0.79	0.912
A7	56.04	182.95	0.74	0.911
A8	55.95	188.33	0.68	0.913
A9	55.67	185.32	0.72	0.912
A10	55.46	181.25	0.79	0.910
A11	56.27	192.30	0.55	0.916
A12	55.76	201.25	0.31	0.923
A13	56.79	196.55	0.44	0.919
A14	55.72	194.96	0.51	0.918
A15	55.30	191.07	0.72	0.913
A16	56.48	203.01	0.32	0.921
A17	55.46	197.96	0.46	0.918
A18	55.18	197.77	0.52	0.917

Based on this column, it is clear that all items contribute to scale reliability. Removing any item does not positively affect the reliability of the scale. Thus, it was not necessary to remove any of the items that made up the 18-item scale. After the scale was determined to be understandable and reliable, the main study was performed.

The demographics of the 193 participants of the main study are shown in Table 5.

3.1.2. Structuring and Assessment of the Scale

The scale structure was created *via* EFA and CFA.

In order to test the suitability of the data for factorization, Kaiser-Meyer-Olkin (KMO) and Bartlett's sphericity tests were applied using the SPSS 23.0 statistical software. A KMO value of 0.50 is the accepted lower limit of the KMO test [57]. A value that approaches 1.0 indicates a perfect fit for factorization. Additionally, a significant p-value ($p<0.001$) is expected from the Barlett sphericity test.

In this study, the results from the KMO test (0.852) were found to be close to perfect and the results from Bartlett's test (Bartlett's test of sphericity=1438.232, DF=153, $p<0.001$) were found to be significant. These results showed that the obtained data was suitable for factor analysis, which was performed using a principal component method and varimax rotation.

To understand which items have strong correlations to which factors, the acceptance levels of the factor load values of items were theoretically determined as suggested by Çokluk et al. [58]. First, items with load values below 0.40 were deleted from the scale. Second, if an item was involved with two factors, the factor with the highest item load value was selected. However, if the difference

Table 5. *Demographics of study respondents*

Characteristics	Category	Quantity	Percent (%)
Gender	Male	173	90
	Female	20	10
Age	18-24	3	2
	25-35	65	34
	36-45	95	49
	46 and above	30	15
Education	High school	9	5
	Associate degree	18	9
	Bachelor's degree	137	71
	Postgraduate	29	15
Occupation/Department	DPA	55	28
	Operation department	49	25
	Technical department	32	17
	Chartering department	22	11
	Human resources department	16	8
	Purchasing department	7	4
	Accounting department	2	1
	General director	6	3
	Fleet manager	3	2
	Agency manager	1	1
Working year	1-3	74	38
	4-9	77	40
	10-15	27	14
	16 and above	15	8
Company generation	1st generation	107	55
	2nd generation	63	33
	3rd generation	20	10
	4th generation	3	2

DPA: Designated person ashore

between factor values was greater than 0.1, that item was deleted from the scale. Based on the factor analysis, four items (A1, A6, A12, and A15) that had factor load values less than 0.40 or a difference in factor load values greater than 0.1 were deleted, and the study proceeded with 14 items.

Results from the KMO and Barlett tests for the 14 items (KMO value=0.857 and Bartlett's test of sphericity=1204.443, DF=105, p<0.001) demonstrated that the data was suitable for factor analysis. A scale was formed by three factors using a principal component method and varimax rotation. The contribution to variance of the three factors was 57.268%, which was above the acceptable level of 0.50 [58]. The factor analysis results (Table 6) showed that factor load values of all items were above the acceptable level of 0.40.

To test the reliability of the scale, Cronbach's alpha coefficient was calculated and determined to be 0.878 (Table 7). Moreover, the reliability levels of each factor in the scale were also measured. Cronbach's alpha coefficient for the three factors (EOS=0.707, TA=0.768, IA=0.838) were all above 0.70. Thus, all results from the reliability analysis were found to be satisfactory [55].

CFA was performed after EFA. This analysis is used to measure the adequacy of the relationship between the factors determined by EFA, the relationship of variables with factors, the interdependence of factors, and the adequacy of the factors to explain the model [59]. Therefore, CFA is a measurement tool for the structural validity of the scale [60]. Here, SEM was used to apply CFA to understand construct validity. SEM, which was implemented using various statistical programs, tests the relationships in CFA described above, using path analysis [60]. A SEM model was set up using these programs for path analysis. Next, the fit indices of the established model were examined. Model fit indices were verified based on suggested literature values [60]. A SEM model (Figure 1) was established for CFA using the AMOS 23.00 Statistical Program.

The model fit indices of the study were chi square/degrees of freedom (χ^2/df)=1.76, standardized root mean square residual (SRMR)=0.059, comparative fit index (CFI)=0.94, goodness of fit index (GFI)=0.91, Tucker-Lewis index (TLI)=0.93. All model fit indices (Table 8) were determined to be satisfactory [58-61]. In addition, all items shown in Table 9 were found to be statistically significant (p<0.001).

Table 6. *Exploratory factor analysis results*

Dimensions	Items		Factor 1	Factor 2	Factor 3
Effective Organizational Structure (EOS)	EOS1	The mission and vision of our company are known by all employees.	0.575		
	EOS2	The duties, authorities, and responsibilities of the employees in our company are written in detail.	0.807		
	EOS3	Our company's seafarers and office employees are recruited by experts.	0.551		
	EOS4	Our company has a fair promotion policy for all employees.	0.728		
	EOS5	In our company, a fair wage policy is applied for all employees, whether they are family members or not.	0.715		
	EOS6	The resignation of one of the company employees does not affect the work flow of our company.	0.682		
Transfer of Authority (TA)	TA1	Employees in our company can transfer their authority and responsibilities to other employees, if necessary.		0.853	
	TA2	Employees of our company know whom to transfer their authority and responsibilities, if necessary.		0.744	
	TA3	Employees of our company can take initiative without asking their superiors.		0.607	
	TA4	Our company has a reward and punishment system for employees.		0.526	
Internal Audit (IA)	IA1	Internal audits in our company are carried out effectively.			0.736
	IA2	Our seafarers have sufficient knowledge about the function and requirements of the ISM code.			0.629
	IA3	Any non-conformity that arises during internal audits conducted in accordance with the requirements of the ISM code in our company is not repeated on our ships.			0.794
	IA4	Corrective actions of found non-conformities are carried out as soon as possible regardless of present market conditions.			0.724
ISM: International Safety Management Code					

Table 7. *Reliability analysis results*

Factors and scale	Reliability
Effective organizational structure	0.707
Transfer of authority	0.768
Internal audit	0.838
Institutionalization level scale	0.878

Table 8. *Model fit indices*

Indices	Acceptable values	Confirmatory factor analysis model indices	Source
Chi-square/Degrees of freedom (CMIN/Df)	$0 \leq \chi^2/df \leq 3$	1.76	[61]
Standardized root mean square residual (SRMR)	SRMR≤0.08	0.059	[62]
Comparative fit index (CFI)	0.90≤CFI≤1.00	0.94	[63]
Goodness of fit index (GFI)	0.90≤GFI≤1.00	0.91	[64]
Tucker-Lewis index (TLI)	0.90≤TLI≤1.00	0.93	[61]

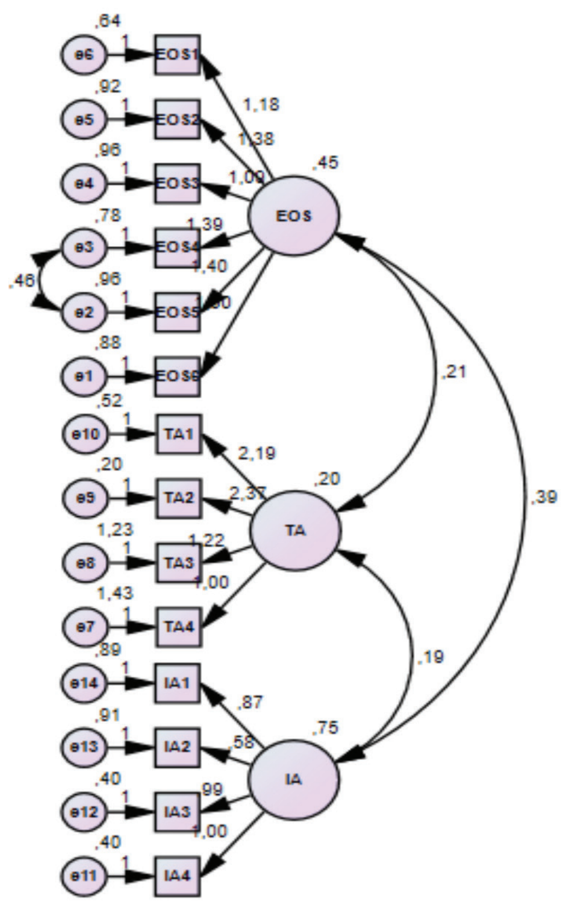

Figure 1. *A confirmatory factor analysis model with structural equation modeling*

EOS: Effective organization structure, TA: Transfer of authority, IA: Internal audit

Based on these results, the scale was determined to be structurally valid.

This analysis was also used to understand the discriminant validity of the factors by comparing the correlation coefficients. Discriminant validity explains that factors in a scale measure different phenomena. The correlation between any two dimensions must be less than 0.85 for discriminant validity [65]. As seen in Table 10, the correlation between each dimension was less than 0.85.

The factor correlations were found to be statically significant (p<0.001); thus, the scale also passed the discriminant validity test.

Based on the EFA and CFA, we conclude that the developed institutionalization level scale for maritime family businesses is reliable and valid.

4. Discussion

In this study, a reliable and valid institutionalization level scale was developed for family-owned ship management companies. The originality of this study can be evaluated

Table 9. *Regression weights for the confirmatory factor analysis model*

			Estimate	S.E.	C.R.	P
EOS6	<---	EOY	1.000			
EOS5	<---	EOY	1.399	0.196	7.127	***
EOS4	<---	EOY	1.386	0.188	7.360	***
EOS3	<---	EOY	1.087	0.167	6.493	***
EOS2	<---	EOY	1.384	0.193	7.189	***
EOS1	<---	EOY	1.176	0.163	7.234	***
TA4	<---	TA	1.000			
TA3	<---	TA	1.224	0.314	3.903	***
TA2	<---	TA	2.367	0.499	4.740	***
TA1	<---	TA	2.194	0.466	4.709	***
IA4	<---	IA	1.000			
IA3	<---	IA	0.988	0.095	10.357	***
IA2	<---	IA	0.580	0.096	6.051	***
IA1	<---	IA	0.866	0.105	8.222	***

***P<0.001
S.E.: Standard error, TA: Transfer of authority, IA: Internal audit

Table 10*. Analysis results of discriminant validity*

Factors	Correlations		
	Effective organizational structure	Transfer of authority	Internal audit
Effective organizational structure	1		
Transfer of authority	0.68***	1	
Internal audit	0.67***	0.49***	1

***P<0.001

based on several aspects. Previous studies that examined institutionalization or corporate governance in maritime businesses generally considered the presence of a CEO on the board as corporate governance [10]. In contrast to the literature, we evaluated the attitudes of company employees, not the company owners or board members, to prevent biased assessments that can occur when company owners evaluate their own businesses. By measuring the current corporate status of companies using this scale, the stages of corporate governance with deficiencies can be determined. Additionally, the relationships between institutionalization levels and managerial factors, which have been previously examined [12-16], can be examined within the scope of maritime businesses.

Non-family-owned businesses, where the majority of a company's shares are not owned by the family or at least two generations of the family do not work in the company, have also been studied [66]. Some studies have shown that the institutionalization levels of family-owned businesses are better than that of non-family-owned businesses, and that they may have more performance advantages [7,67,68]. Thus, the difference in institutionalization levels between family and non-family-owned ship management companies can be examined within the scope of maritime businesses.

5. Conclusion

Since maritime market conditions are constantly changing, it is important that ship management companies can adapt to these conditions to exist in the future. Family businesses, which have an important role in the maritime industry, need to establish certain standards in their managerial structures to adapt to these market conditions.

Institutionalization can ensure that these standards are created and integrated into the organizational culture. Hence, it is important to evaluate the current corporate governance status of businesses for institutionalization.

In this study, a scale was developed to measure the institutionalization level of family-owned ship management companies. The scale development process was conducted in the following two stages: item generation and questionnaire design and the structuring and assessment of the scale. Literature reviews and in-depth interviews with experts were conducted for item generation and questionnaire design. The items that comprise this scale were determined as institutionalization indicators for family-owned ship management companies and are listed in Table 6.

Since maritime businesses have unique structures, institutionalization indicators were evaluated based on this structure. In the maritime industry, the ISM code was developed to achieve standardization for ship management companies. The ISM code is a quality management system and is expected to trigger businesses to cooperate with management; however, this is not always the case due to human factors. Both office employees and seafarers have intense working conditions. Thus, rewarding employees for their success in these conditions can initiate the function of the system. Studies show that employees who are family members in family businesses are positively discriminated against. Having a fair wage and promotion policy for all employees, whether they are family members or not, can contribute to the function of the system by increasing employee commitment to work. These practices can reduce personnel turnover rates by contributing to employee acquisition of organizational culture.

Conversely, maritime businesses have a hierarchical structure among employees. This hierarchy is considered important for the success of a maritime business. However, in this hierarchy, it is important for employees to be able to transfer power and to take initiative. Employees not only relieve the workload of supervisors, but also provide a sense of achievement and job satisfaction for those that work under them. However, the limits of the transfer of authority should be determined within the structure of the business itself. Having a punishment system against negative situations that may occur when these authority limits are exceeded can prevent these situations from occurring during system operation. In addition, the resignation of an employee in this hierarchical structure should not disrupt the workflow of the company. Therefore, for both institutionalization and the ISM code, it is necessary to operate in accordance with a specific system, and not by individuals.

In the items prepared for the institutionalization scale, the importance of professionalism was emphasized. Recruitment by experts is necessary in the corporate governance approach. To work on ships, seafarers must have a certification; however, these certificates alone do not predict the success of a seafarer in the system. Studies report that the majority of maritime accidents are caused by human error.

Thus, ship management companies must develop effective recruitment systems that are created and standardized by experts. These systems should also be applied to recruit office employees into effective management systems. Additionally, since the ISM code includes rules for the safety of seafarers, it is beneficial to inform and to train seafarers on these issues to reduce human error. Standardizing these practices will bring businesses closer to institutionalization.

Audits in maritime businesses are conducted in accordance with international regulations. Ships or companies are faced with certain sanctions against non-conformities found in external audits. These sanctions negatively affect the operational and financial performance of businesses. As a precaution against these sanctions, businesses should carry out internal audits as recommended in the ISM code. However, market and financial conditions of ship management companies may delay their responses to corrective actions. Regardless, timely implementation of corrective actions will prevent potential major losses. Additionally, a non-conformity found on one ship that is not repeated on other ships may indicate that the company has carried out internal audits and implemented corrective actions.

Theoretical and Practical Contributions

We developed a reliable and valid data collection tool with a new perspective for a specific field. Previously, only a qualitative method was evaluated to develop a model for the institutionalization levels of maritime businesses [9]. In our study, we developed a reliable and valid scale for institutionalization levels using quantitative methods. We obtained data from office employees rather than shipowners in ship management companies to prevent evaluation bias from shipowners. Additionally, employees are the workers that actually perform the assigned jobs in a company. Therefore, our study also fills a gap in the literature by addressing a different aspect of institutionalization studies in maritime family businesses. Moreover, Tagiuri and Davis [69] characterized family businesses as the institutionalization of the family, institutionalization of the businesses, and institutionalization of ownership. In this study, we focused and measured the institutionalization level of the business in maritime family businesses.

This scale is applicable to maritime family businesses and can be used in practice. Owners or senior managers of maritime family businesses can apply this scale to evaluate low attitudes based on employee answers. Thus, practices that negatively affect institutionalization in the organization can be identified and corrected.

The answers given by participants (1: completely disagree to 5: strongly agree) will determine the level of institutionalization of the business. The level of institutionalization will increase as the answers to the scale approach 5.

Recommendations for Further Research

Different relationship analyses (e.g., institutionalization level and firm performance, human resource applications, strategic management, leadership, organizational culture, and corporate social responsibility) can be performed using the data collection tool presented in this study. Accordingly, the institutionalization levels of different types of ship management companies (e.g., family owned *vs.* non-family owned) can be compared. In addition, each institutionalization indicator of the ship management companies obtained within the scope of this study can be considered as a criterion and analyzed *via* multicriteria decision-making methods. Finally, this scale can be diversified by quantitative studies on the institutionalization of family and ownership in ship management companies.

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Authorship Contributions

Concept design: B. Demir, L. Tavacıoğlu, Data Collection or Processing: B. Demir, L. Tavacıoğlu, Analysis or Interpretation: B. Demir, L. Tavacıoğlu, Literature Review: B. Demir, L. Tavacıoğlu, Writing, Reviewing and Editing: B. Demir, L. Tavacıoğlu.

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Effects of Power Distance on Organizational Commitment: A Study on Maritime Faculty Students

Umut Yıldırım[1], Arda Toygar[2], Ahmet Lutfi Tunçel[3]

[1]Karadeniz Technical University Surmene Faculty of Marine Sciences, Department of Maritime Transportation and Management Engineering, Trabzon, Turkey
[2]Artvin Coruh University Hopa Vocational School, Maritime and Port Management Program, Artvin, Turkey
[3]İstanbul Technical University Maritime Faculty, Department of Maritime Transportation and Management Engineering, İstanbul, Turkey

Abstract

This study investigates the effect of power distance on the organizational commitment of maritime faculty students. The hypotheses developed in this context were analyzed using the structural equation modeling method based on data collected from 406 participants. The results from one-dimensional (1D) evaluation indicated that organizational power distance had a positive impact on the organizational commitment levels of maritime faculty students. However, there are several studies in the literature that show that this effect may lead to inconsistent results in 1D examination. These conflicting results necessitate a multidimensional analysis of the research. Evaluation of the sub-dimensions included in the study revealed that: (1) acceptance of power had positive effects on calculative and moral commitment, (2) justification of power on moral commitment, and (3) acquiescence of power on calculative, alienative, and moral commitment.

Keywords

Organizational commitment, Power distance, Maritime, Education, Vocational training

1. Introduction

Although various factors that influence the academic performance of students have been discussed in the literature, the commitment of students to the educational institution is the most important one [1,2]. Because it increases students' loyalty levels, leading to superior performance [3]. Besides, powerful commitments that individuals establish with their superior managers also positively affect their performance [4]. Educational institutions, defined as organizations for students, are both centers of science and theoretical knowledge and essential business partners that benefit working life. Vocational education differs from traditional education, integrating with working life [5]. Maritime faculties provide vocational education in cooperation with the maritime industry. Maritime customs play a significant role in the formation of this educational understanding [6]. These manners and traditions emerged due to the requirements of marine life experienced and learned on ships throughout history. Moreover, maritime faculty students spend at least 6 to 12 months on a maritime internship during their undergraduate education, which differentiates them from students in other departments. Although the education understanding in maritime faculties differs significantly from that in other faculties, few studies in the literature examine the effects of this difference on students' levels of organizational commitment. Maritime faculties are among organizations that encourage hierarchical formation and subordinate-superior relationships based on specific rules, where the power distance difference is important. The literature has reported that organizations with a high power distance have negative effects on individuals [7]. Conversely, some studies revealed that organizations with high power distance levels positively affected individuals [8]. In order to eliminate this inconsistency, a multidimensional analysis should be used to investigate the impact of power

Address for Correspondence: Umut Yıldırım, Karadeniz Technical University Surmene Faculty of Marine Sciences, Department of Maritime Transportation and Management Engineering, Trabzon, Turkey
E-mail: uyildirim@ktu.edu.tr
ORCID ID: orcid.org/0000-0002-3991-5457

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distance on organizational commitment levels. In models where organizational power distance and commitment are constructed in one dimension (1D), the results do not represent the relevant concepts in either theoretical or practical frameworks [9]. Therefore, in the current study, the multidimensional analysis was applied to investigate the effects of power distance on students' organizational commitment. Unlike 1D evaluation, the results of this study suggest that organizational power distance can have a positive impact on organizational commitment. Further, this study is one of the first systematic attempts to investigate the organizational commitment levels of maritime faculty students in organizations with high power distances.

This paper is divided into the following sections: in the second section, the concepts related to the subject of the study are explained, and the literature studies are discussed. The third section includes arguments supporting the hypothetical effect of power distance on organizational commitment and its sub-dimensions, as well as the proposed research hypotheses and model. The fourth and fifth sections include the research methodology, analysis, and findings. The conclusion section presents the results of the study, its implications, and recommendations for future studies.

2. Concepts and Theoretical Background

2.1. Organizational Power Distance

The concept of power distance has been defined in different contexts. According to one of these definitions, it can be expressed as the extent to which individuals perceive themselves as equal to the rest of society [10]. In other words, power distance shows how societies handle the fact that people are not seen as similar when considering all their characteristics [11]. Besides, the formation of organizations shaped by society is another definition of power distance. Various factors determine the power distance perceptions of societies. For example, in addition to the status of individuals, the belief and cultural structure of a society can also affect individuals' perception of power [12]. Power distance is significant in social life, including work, education, and other organizational structures where hierarchical structures are constructed. Moreover, organizational power distance significantly affects the relationships between individuals who do not have the same power level. Hofstede [13] stated that while the subordinate-superior relationship in workplaces has an educational and practical basis in societies with a low power distance, the cause of this relationship was primarily emotional in societies with a high power distance.

2.2. Organizational Commitment

The commitment of individuals to their organizations is very significant for organizations, leading organizational commitment as one of the main topics in the related literature [14]. Organizational commitment is defined as the commitment of individuals to the organization that they work for [15]. There are various definitions and perspectives of organizational commitment in the literature. Sheldon [16] defined organizational commitment as an evaluation of the goals set by the organization from a positive perspective, whereas Buchanan [17] defined it as an emotional bond developed with the structure of the organization. Çöl and Gül [18] suggested that the reason for different evaluations of organizational commitment in the literature is the interpretation of this concept from different perspectives by other disciplines, such as psychology, sociology, and organizational behavior. There are several theories in the literature on organizational commitment. Etzioni [19] argued that the foundations of organizational commitment were constructed by categorizing it as alienative, moral, and calculative. Penley and Gould [20], investigating the basis of these three concepts, proposed that alienative and moral commitment can reveal emotional aspects of individuals while calculative commitment can determine instrumental aspects.

3. Theoretical Basis and Research Hypotheses

There are numerous studies in the literature on the effects of power distance on individuals' organizational commitment. Some studies argue that organizations with a high power distance negatively affect the commitment levels of individuals [21]. For instance, Yıldırım and Deniz [22] analyzed these effects based on data collected from 1094 participants. According to the results of their analysis, it was concluded that organizational power distance had a negative effect on commitment levels. However, other studies showed that organizations with a high power distance have a positive impact on commitment levels [23]. For example, a study by Din et al. [24] using data collected from 300 participants indicated that commitment levels would be high in organizations with a high power distance. The main hypothesis developed in the present study to eliminate this inconsistency in the literature is as follows:

H_1: Organizational power distance has a positive effect on the organizational commitment levels of maritime faculty students.

To fully examine the concept of organizational power distance, the sub-dimensions of acceptance power, instrumental use of power, justification of power, and acquiescence of power developed by Yorulmaz et al. [12] were used in the present study. For organizational commitment, we used the sub-dimensions of calculative commitment, alienative commitment, and moral commitment developed by Penley and Gould [20]. Acceptance of power is the acquiescence of individuals working at different levels in the same organization to the unequal power distribution [12]. Calculative commitment is when the organization is used as a tool to achieve an individual's targeted interests [25]. Duska [26] defined alienative commitment as the lowest commitment level. Conversely, those with alienative commitment have to be in the organization, even if they cannot be internalized and cannot establish a relationship with it. Etzioni [19] argued that the strongest commitment type is a moral commitment. In moral commitment, individuals in the organization give precedence to the goals of the organization, internalizing them in their voluntary willingness to serve the organization [27]. Jaros et al. [9] argued that individuals with a high moral commitment level have an increased sense of duty and a high organizational commitment level. Thus, the following sub-hypotheses are developed:

$H_{1.1}$: Acceptance of power has a positive effect on the calculative commitment levels of maritime students.

$H_{1.2}$: Acceptance of power has a positive effect on the alienative commitment levels of maritime students.

$H_{1.3}$: Acceptance of power has a positive effect on the moral commitment levels of maritime students.

Instrumental use of power neglects ethical values in the struggle to achieve determined goals [28]. According to this understanding, an individual contributes to the organization to benefit from the opportunities provided. The possibility-contribution exchange realized by the individual to achieve their goal constitutes the concept of instrumental commitment. In cases where such an understanding is seen in an organization, superiors need to understand the culture of the organization and protect its interests [29]. Also, the level of instrumental use of power corresponds to the ratio of the organization's demands met by the individual [20]. For this reason, the following sub-hypotheses are proposed to determine the effects of instrumental use of power on the organizational commitment of maritime students:

$H_{1.4}$: Instrumental use of power has a positive effect on the calculative commitment levels of maritime students.

$H_{1.5}$: Instrumental use of power has a positive effect on the alienative commitment levels of maritime students.

$H_{1.6}$: Instrumental use of power has a positive effect on the moral commitment levels of maritime students.

Justification of power is such that the individuals working in managerial positions make employees accept their authority on legal grounds. In addition to the search for legal grounds, identifying societies' cultural structures and positions with individuals leads to the justification of power [30]. Wang et al. [8] emphasized that the relationship between subordinates and superiors can affect their organizational commitment levels; this effect will be a determining factor for the performance levels of subordinates. Moreover, Bedürk and Ertürk [31] argued that organizational power distance and its sub-dimensions are likely to be high when subordinates accept the leadership of their superiors in the intra-organizational subordinate-superior relationship. Furthermore, Pomyalova et al. [32] determined that the culture formed in the hierarchical structure directly reduces students' commitment levels. Thus, considering the inconsistency in the literature, the following sub-hypotheses are proposed:

$H_{1.7}$: Justification of power has a positive effect on the calculative commitment levels of maritime students.

$H_{1.8}$: Justification of power has a positive effect on the alienative commitment levels of maritime students.

$H_{1.9}$: Justification of power has a positive effect on the moral commitment levels of maritime students.

Acquiescence of power is defined as acquiescence of superior dominance in the groups with hierarchical structure [33]. Acquiescence of power emerges from the perception that the probability of changing management practices is weak in societies where fear is dominant or the potential to encounter risks is high. Randall [34] deduced that a high level of fear toward an organization could have a negative impact on both individuals and the organization. The following sub-hypotheses are proposed:

$H_{1.10}$: Acquiescence of power has a positive effect on the calculative commitment levels of maritime students.

$H_{1.11}$: Acquiescence of power has a positive effect on the alienative commitment levels of maritime students.

$H_{1.12}$: Acquiescence of power has a positive effect on the moral commitment levels of maritime students.

In this study, multidimensional evaluation was applied to investigate the effects of power distance on organizational commitment in the context of the main and sub-dimensions. The structures and interdimensional relations in the proposals were created using literature. Figure 1 presents the proposed models and hypotheses.

4. Methodology

4.1. Instrument and Questionnaire Design

The online questionnaire method was used as the primary data collection to examine all aspects of the topic used in this research, and two different scales with appropriate features were applied. The first scale is the "organizational power distance scale (OPDS)," prepared by Yorulmaz et al. [12], and the second scale is the "organizational commitment scale (OCS)" developed by Penley and Gould [20] and translated into Turkish by Ergün and Çelik [27]. The items in the scales were scored using the 5-point Likert format, where 1 indicates "I strongly disagree" and 5 indicates "I strongly agree."

4.2. Sampling and Data Collection

The research population consists of the maritime faculty students in Turkey. The sampling method used in this study is non-probability sampling, also known as convenience sampling, where data is collected from the participants until the desired number of participants is reached. The questionnaire forms were collected from the participants between November and December 2020 using web-based questionnaire method. Among 434 questionnaires collected, 28 were excluded due to incomplete or incorrect or a lack of consistency. Thus, the sampling group in this study consists of 406 questionnaires, i.e., 93.5% of the completed questionnaires. Regarding the demographic distribution of the sampling group, the majority of the respondents (54.4%) are aged between 20 and 22, with 24.9% in the 1st grade, 20% in the 2nd grade, 22.9% in the 3rd grade, 25.6% in the 4th grade, and 6.7% in the 5th grade. Examining the distribution of academics considered as managers by the respondents, 7.8% of students consider their advisor as a manager, with 7.7% for research assistants, 14.1% for faculty members, 30.7% for the head of the department, 21% for the dean, and 18.5% for the rector.

4.3. Sample Size Calculation

According to the sample size table developed by Sekaran and Bougie [35], when the research population is larger than 1 million, 384 participants can adequately represent the research population. Prior to data collection, the target number of participants for the sample size was referenced based on Sekaran and Bougie's [35] study in the literature. In addition, to determine whether the sample size was sufficient for the research after the data collection, a power analysis was carried out using the "Power-3.1.9.2" software. Following data collection, the analysis was performed at an 80% confidence level. Accordingly, the effect size of the study was calculated using post-hoc (linear multiple regression) power analysis based on the explanatory power of the hypotheses that were found to be significant in the SEM analysis. Using the lowest effect size of 0.015, the power of the research was determined to be 0.70. According to Cohen [36], the minimum value required in studies involving post-hoc power analysis is 0.67. Given that the statistical power for the related post-hoc power analyses ranged between 0.75 and 0.99, it was determined that the study reached a sufficient number of samples. The results indicated that a sample group of 406 participants would adequately represent the research population.

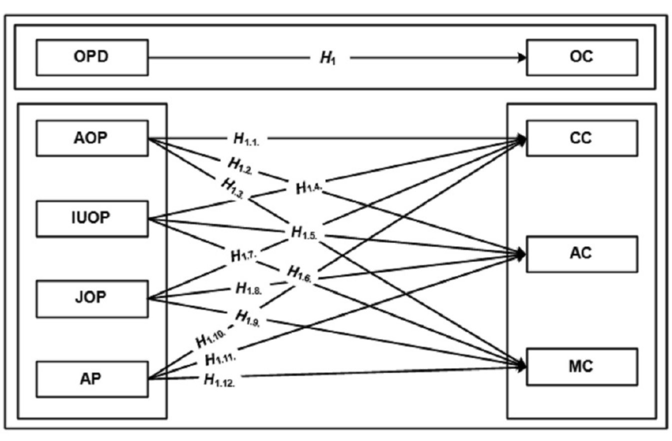

Figure 1. *Research model*

OPD: Organizational power distance, OC: Organizational commitment, AOP: Acceptance of power, IUOP: Instrumental use of power, JOP: Justification of power, AP: Acquiescence of power, CC: Calculative commitment, AC: Alienative commitment, MC: Moral commitment

5. Results

5.1. Confirmatory Factor Analysis Findings for The OPDS and OCS

Confirmatory factor analysis (CFA) was performed based on the data obtained from the 406 participants to examine the validity of factor structures explained by OPDS and OCS using the primary data and to determine if the original structure of the scales matched with the data collected [37]. In this context, two different measurement models, the OPD (4 sub-dimensions 17 items) and the OC (3 sub-dimensions 13 items) scales, were tested with CFA analysis. Tables 1 and 2 summarize the results of the analysis.

According to the CFA results, the factor loadings of the items vary between 0.65 and 0.96, 0.70 and 0.95, respectively, for OPDS and OCS, as presented in Table 1. These standardized factor loadings are significant at the 0.001 level [38]. In this study, the method proposed by Bagozzi and Yi [39] was used to obtain reliable results from structural equation modeling analysis. The average variance extracted (AVE) and composite reliability (CR) values were examined to determine the convergent validity of the measurement models. Table 2 shows that the AVE values for the sub-dimensions of OPDS and OCS vary between 0.63 and 0.80, including the CR varies between 0.83 and 0.98, indicating that the AVE is at satisfactory levels for convergent validity and the CR is considerably above the lower limit [40]. The internal consistency of the sub-dimensions of the OPDS was determined using Cronbach's alpha reliability analysis. To achieve reliable results, the Cronbach's alpha values of the sub-dimensions of the scale should be greater than 0.70

[41]. The results of the analysis showed that the reliability levels of the sub-dimensions were 0.83, 0.86, 0.84, and 0.92. When the same method was used to the OCS, the sub-dimensions were 0.86, 0.88, and 0.90. It was concluded that the reliability for all sub-dimensions was considerably higher than the specified lower limit. Table 2 shows the fit index criteria obtained from the CFA values of the OPDS and OCS.

For the scale to be accepted, the goodness of fit criteria must be greater than the minimum acceptable limits.

Table 1. *Standardized item loadings, AVE, CR, and Alpha values*

Scale	Sub dimension	Item	Factor loading (CFA)	AVE	CR	Cronbach's Alpha
OPDS	AOP	AOP1	0.96	0.63	0.91	0.83
		AOP2	0.65			
		AOP3	0.88			
		AOP4	0.66			
		AOP5	0.78			
		AOP6	0.78			
	IUOP	IUOP1	0.85	0.69	0.87	0.86
		IUOP2	0.75			
		IUOP3	0.89			
	JOP	JOP1	0.95	0.69	0.87	0.84
		JOP2	0.73			
		JOP3	0.80			
	AP	AP1	0.90	0.70	0.96	0.92
		AP2	0.85			
		AP3	0.83			
		AP4	0.81			
		AP5	0.80			
OCS	CC	CC1	0.95	0.63	0.83	0.86
		CC2	0.70			
		CC3	0.71			
	AC	AC1	0.94	0.80	0.98	0.88
		AC2	0.90			
		AC3	0.90			
		AC4	0.90			
		AC5	0.82			
	MC	MC1	0.89	0.73	0.96	0.90
		MC2	0.85			
		MC3	0.87			
		MC4	0.83			
		MC5	0.83			

OPDS: Organizational power distance scale, OCS: Organizational commitment scale, AOP: Acceptance of power, IUOP: Instrumental use of power, JOP: Justification of power, AP: Acquiescence of power, CC: Calculative commitment, AC: Alienative commitment, MC: Moral commitment, AVE: Average variance extracted, CFA: Confirmatory factor analysis

Table 2. *The recommended and actual values of fit indices*

Fit criteria	χ^2/df	RMSEA	CFI	GFI	AGFI	NNFI	NFI	RMR	SRMR
Recommended values	≤3***	<0.10**	≥0.9**	≤1**	≤1**	≤1**	≥0.9*	≤0.10**	≤0.05**
Actual values (OPDS)	2,574	0.062	0.98	0.93	0.91	0.98	0.97	0.051	0.043
Actual values (OCS)	2,779	0.066	0.99	0.94	0.91	0.98	0.98	0.048	0.041

*[40], **[42], ***[43].

OPDS: Organizational power distance scale, OCS: Organizational commitment scale, RMSEA: Root mean square error of approximation, GFI: Goodness-of-fit index, CFI: Comparative fit index, AGFI: Adjusted goodness of fit index, RMR: Root mean square residual, SRMR: Standardized root mean square residual

When the fit criteria values for the OPDS were obtained, it was determined that the most crucial fit value, the ratio of X^2 to standard deviation (SD), was at the perfect level (2.574), the RMSEA value (0.062) was at an acceptable level, and the other fit values were also at perfect and acceptable levels [42,43]. When the CFA results for the OCS were examined, it was found that the ratio of X^2 to sd was at the perfect level (2.779), the RMSEA value (0.066) was at an acceptable level and the other fit values were at perfect and acceptable levels. These results show that the factor structures explained for both OPDS and OCS were validated [40,42,43].

Table 3. *Main hypothesis results*

Structural path	Hypothesis	Standard value	T-value	Supported or not
OPD→OC	H_1	0.64	5.85*	Yes
OPD: Organizational power distance, OC: Organizational commitment				

5.2. The Structural Model

After the scales were validated with measurement models using CFA, in this section, 1 main and 12 sub-hypothesis proposed within the scope of the study were tested using two different latent structure models. The Lisrel 8.7 program was used in structural equation modeling and validity and reliability analysis. The first hypothesis was tested in the model involving OPD and OC latent variables, while 12 sub-hypotheses were tested using latent variables representing sub-dimensions. Table 3 and 4 present the path coefficients and variance values of the latent variables in the models.

Figure 2 depicts the first path diagram for the main hypothesis whereas the chi-squared value (χ^2=32.88) and standard deviation (SD=14) are shown in Table 3. The ratio of the chi-squared value to the degrees of freedom (χ^2/SD=2.348) is less than 3, indicating a perfect fit. Other goodness of fit indices for the structural model indicates that the established model gives a perfect fit. Figure 3

Table 4. *Sub-hypotheses results*

Structural path			Hypothesis	Standard value	T-value	Supported or not
AOP	→	CC	$H_{1.1.}$	0.17	2.98*	Yes
AOP	→	AC	$H_{1.2.}$	0.04	0.80	No
AOP	→	MC	$H_{1.3.}$	0.24	4.29*	Yes
IUOP	→	CC	$H_{1.4.}$	0.05	0.83	No
IUOP	→	AC	$H_{1.5.}$	-0.08	-1.35	No
IUOP	→	MC	$H_{1.6.}$	0.02	0.36	No
JOP	→	CC	$H_{1.7.}$	0.01	0.17	No
JOP	→	AC	$H_{1.8.}$	0.06	1.18	No
JOP	→	MC	$H_{1.9.}$	0.12	2.31*	Yes
AP	→	CC	$H_{1.10.}$	0.17	2.82*	Yes
AP	→	AC	$H_{1.11.}$	0.18	3.04*	Yes
AP	→	MC	$H_{1.12.}$	0.16	2.68*	Yes
IUOP: Instrumental use of power, AOP: Acceptance of power, JOP: Justification of power, AP: Acquiescence of power, CC: Calculative commitment, AC: Alienative commitment, MC: Moral commitment						

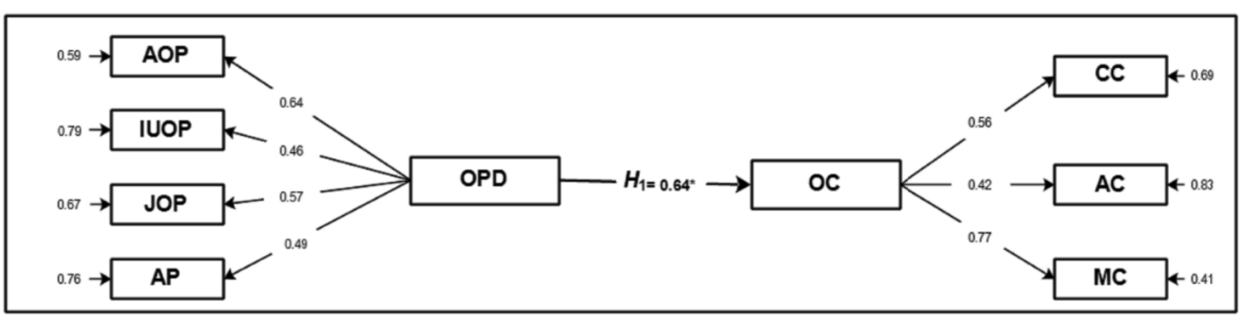

Figure 2. *Path diagram for the main hypothesis*

Chi-square=32.88, df=14, p-value=0.00101, RMSEA=0.066

IUOP: Instrumental use of power, AOP: Acceptance of power, JOP: Justification of power, AP: Acquiescence of power, CC: Calculative commitment, AC: Alienative commitment, MC: Moral commitment, OPD: Organizational power distance, OC: Organizational commitment

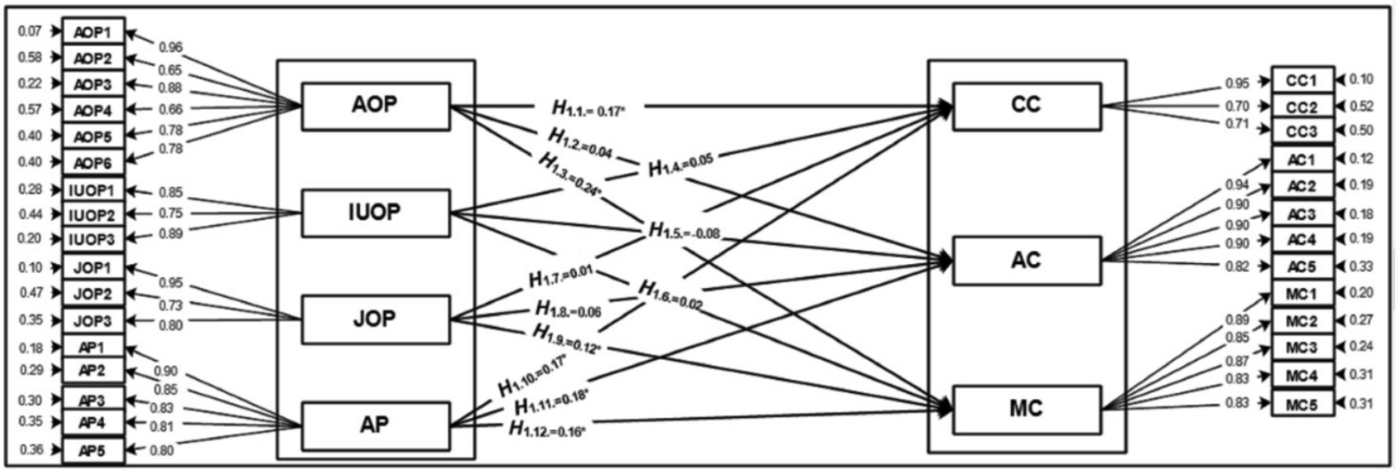

Figure 3. *Path diagram for the sub-hypotheses*

Chi-square=769.73, df=386, p-value=0.00000, RMSEA=0.050

IUOP: Instrumental use of power, AOP: Acceptance of power, JOP: Justification of power, AP: Acquiescence of power, CC: Calculative commitment, AC: Alienative commitment, MC: Moral commitment

presents the second path diagram for the sub-hypotheses whereas the chi-squared value (χ^2=769.73) and standard deviation (SD=386) are presented in Table 4. The ratio of the chi-squared value to the degrees of freedom (χ^2/SD=1.994) is less than 3, indicating a perfect fit. The other goodness of fit indices for the structural model indicates that the established model gives a perfect fit, as in the first model. The path coefficients of the OPD variable on the OC variable were significant (0.64; $p<0.05$) based on the path analysis results shown in Figure 2. The path analysis results in Figure 3 indicate that the path coefficients of AOP on CC (0.17; $p<0.05$), AOP on MC (0.24; $p<0.05$), JOP on MC (0.12; $p<0.05$), including AP on CC (0.17; $p<0.05$), AC (0.18; $p<0.05$) and MC (0.16; $p<0.05$) were all significant.

Table 3 presents the main hypothesis results for this study, and power distance has a positive effect on the organizational commitment of students. This result indicates that the primary hypothesis H_1 is supported. Table 4 presents sub-hypotheses results. Our findings show that acceptance of power positively affects calculative and moral commitment, supporting sub-hypotheses $H_{1.1.}$ and $H_{1.3.}$ However, $H_{1.2.}$ is not supported because acceptance of power does not affect alienative commitment. The results of the analysis show that instrumental use of power does not affect calculative commitment ($H_{1.4.}$), alienative commitment ($H_{1.5.}$), and moral commitment ($H_{1.6.}$). Although justification of power has a positive effect on moral commitment, it does not have a significant impact on calculative and alienative commitment. Therefore, sub-hypothesis $H_{1.9.}$ is supported, while $H_{1.7.}$ and $H_{1.8.}$ are not. Finally, Table 4 shows that acquiescence of power positively affects calculative, alienative, and moral commitment. For this reason, sub-hypotheses $H_{1.10.}$, $H_{1.11.}$, and $H_{1.12.}$ are supported.

6. Discussion

In this study, the effects of organizational power distance on organizational commitment were examined by considering the sub-dimensions of both concepts. The results of the present study demonstrated that the organizational power distance level of maritime faculty students had a significant and positive effect on their organizational commitment. These results are similar to those for some studies reported in the literature [44,45] and showed that students take the social class they belong to as a criterion while exhibiting their behaviors based on class norms in their institutions. Moreover, the subordinate-superior relationship, one of the important building blocks of maritime customs, has a critical directive effect on their behavior rather than the necessity of legal rules or an egalitarian understanding.

When the sub-hypotheses were evaluated, maritime faculty students' acceptance of power tendency had a positive impact on their calculative and moral commitment. Conversely, no positive effect on their alienative commitment could be identified. These results are in agreement with some literature studies [8,46].

Our data revealed that the instrumental use of power tendency of students did not affect their calculative, alienative, or moral commitment. This result is based on a study showing that a high level of organizational commitment can negatively affect both individuals and organizations [34]. In contrast, a study reports that employees with a high level of emotional organizational commitment adopt behaviors that benefit the organization by combining the organization's goals with their own goals [47].

The present study determined that although the students' tendency toward justification of power had a positive impact on their moral commitment, it did not affect their calculative and alienative commitment. Also, the present study supports the results of a study arguing that a high level of moral commitment in the individual corresponds to a strong bond and sense of duty toward the organization [9]. In this regard, this study could be the first to show that justification of power can have a positive impact on moral commitment.

The present results showed that maritime students' tendency to acquiescence of power positively affected their calculative, alienative, and moral commitments. Further, this result supports those of the study conducted by Bedürk and Ertürk [31]. The discipline, customs, and rules governing the hierarchical structure of an organization can be attributed to the positive effect that students' tendency to acquiescence of power had on their organizational commitment levels. It is possible to obtain such a result from the study because this understanding has long been accepted. Students accept this understanding from the beginning and participate in the organization on their own.

7. Conclusion

In the present research, a multidimensional examination of the effects of power distances, as perceived by maritime faculty students, on their organizational commitment was performed. The main conclusions of the study are as follows:

1. The present results support the previous studies arguing that power distance and organizational commitment do not completely represent the attitudes of participants in one-dimensional models.

2. The results show that although power distance has positive effects on the organizational commitment levels of maritime students, it can have adverse effects in multidimensional evaluations.

3. The results support previous studies that found organizations with high power distance levels to have positive effects on individuals.

4. The organizational power distance perceived by students has a high level of influence on their organizational commitment because students studying in a hierarchical structure establish a strong bond with their institution. Besides, the normative education approach is dominant in the educational institution due to the nature of maritime shows that it has a significant impact on the behavior of students.

5. The results shall contribute valuable information to the literature by identifying the commitment level that students studying in a hierarchical structure have toward their institution and explaining the underlying reasons.

The maritime faculty students are prepared for international working areas. They have their own discipline, customs, and rules and are trained for the difficulties encountered in their working conditions, which differentiate them from those studying other disciplines. To put it more clearly, the organizational commitment levels of students educated in a hierarchical structure may differ from those studying other programs. Therefore, it is necessary to exercise caution when generalizing the results of this study for students in other departments. Moreover, in this study, the factors affecting the organizational commitment levels of maritime faculty students were evaluated only by considering the concept of power distance and its sub-dimensions. The concept of organizational power distance was associated with four sub-dimensions and the concept of organizational commitment with three sub-dimensions. However, other studies in the literature have linked these concepts to different dimensions. Therefore, using different sample groups and dimensions and an extensive examination of the topic would contribute to the literature in future studies.

Authorship Contributions

Concept design: U. Yıldırım, A.L. Tunçel, Data Collection or Processing: U. Yıldırım, A. Toygar, A.L. Tunçel, Analysis or Interpretation: U. Yıldırım, A. Toygar, Literature Review: U. Yıldırım, A. Toygar, A.L. Tunçel, Writing, Reviewing and Editing: U. Yıldırım, A. Toygar, A.L. Tunçel.

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Experimental and Numerical Investigation of the Effects of Different Draft and Wave Frequency Combinations on the Performance of a Fixed OWC Wave Energy Converter

Deniz Öztürk, Mehmet Ozan Şerifoğlu

İstanbul Technical University, Faculty of Naval Architecture and Ocean Engineering, Department of Shipbuilding and Ocean Engineering, İstanbul, Turkey

Abstract

The oscillating water column (OWC) device is a versatile type of wave energy converter, which is one of the promising and popular systems in the use of sustainable supplies of energy. The present research aims to investigate the hydrodynamic performance of a cylindrical OWC device within several approaches, thereby observing the effects of varying wave heights and vertical positions on the flow inside the device. A series of experiments and numerical analyses were performed on a fixed OWC device with an open orifice for three different drafts (0.25, 0.40, and 0.55 m) and regular waves with frequencies ranging between 0.4 Hz and 1.2 Hz. Present results were compared with the results derived from the analytical calculations. The trends observed in the analytical solutions in a response amplitude operator for the heave motion of the internal water free surface with the wave frequency variation for all drafts were consistent with the numerical and experimental results. The findings reveal that the maximum water displacement inside the OWC increases as the draft increases, and the optimal frequency at which this value appears decreases.

Keywords

Oscillating water column, Regular waves, Renewable energy, Computational fluid dynamics, Volume of fluid

1. Introduction

The growing demand for energy consumption in the world requires a rapid increase in energy production. Production through non-renewable sources is not sustainable for future energy needs and can create harmful effects for the environment. As a result, the development of renewable energy sources becomes important to support and replace non-renewable sources. Renewable energy sources can be mainly categorized as hydropower, solar photovoltaic, wind energy, bioenergy, geothermal energy, and ocean energy [1]. Ocean energy consists of ocean current energy, tidal energy, and wave energy. The European Renewable Energy Council stated that the ocean is a very high potential energy source that can meet a significant part of the electricity supply of several European countries [2]. However, energy production using ocean energy stays behind other renewable energy sources. Renewable electricity is 27.3% of the estimated renewable energy share of the global electricity production in 2020, and the ocean energy constitutes the smallest portion with a share of 0.4% [3]. In addition, geothermal power and concentrated solar power are also included in this percentage. The reason why these systems are uncommon is may be due to the inefficiency of ocean energy production methods or the high risks associated with the operation of energy generators. Whatever the reasons are, ocean energy generation should be investigated further and improved to reach its actual potential.

There are numerous types of wave energy generators such as point absorbers, attenuators, overtopping devices, and oscillating water columns [4]. Most of these systems function by transferring the motion of water to a hydraulic or pneumatic power take-off (PTO) system and converting the associated energy to electricity. The oscillating water

Address for Correspondence: Deniz Öztürk, İstanbul Technical University, Faculty of Naval Architecture and Ocean Engineering, Department of Shipbuilding and Ocean Engineering, İstanbul, Turkey
E-mail: ozturkdeni@itu.edu.tr
ORCID ID: orcid.org/0000-0002-6694-3277

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column (OWC) is a type of wave energy generator that works by the exchange of air in and out of a turbine. Air is moved through the turbine by the change of the water level (with the waves) inside the OWC. The rotation of the turbine is then converted to electrical energy. Bidirectional turbines are used to establish continuous turbine rotation in the same direction during reciprocation. The OWC device has three main steps of conversion [5]: wave to pneumatic energy (water to air), pneumatic to mechanical energy (air to turbine), and mechanical to electrical energy (turbine to electricity). OWC generators can be established onshore as a fixed platform or on breakwaters, or they can be built offshore as floating types with various kinds of moorings.

OWC wave energy converters are investigated in numerous studies with various engineering methods, examining the effects of different cross sections, dimensions, turbine types, and fields of operation. McCormick [6] presented a theoretical model for the wave height-power relationship in floating OWC devices. In the study, the compressibility of air is neglected to simplify the physical phenomenon, so the effects caused by viscosity were not observed in the results. However, the approach is very useful in giving a preliminary idea about the power produced by the buoy. Afterward, the author modified the theory in [7,8] in the light of the experimental studies. Martins-Rivas and Mei [9] studied the effects of the incident wave angle for a circular OWC fixed at the end of a breakwater and found that the angle of incidence is not important in the energy production for the studied OWC geometry. In a parallel study, Martins-Rivas and Mei [10] also inspected the impacts of the coastline on the absorption of the wave power by analyzing an OWC fixed on a vertical cliff. They computed and compared coefficients of radiation damping, chamber pressure, and apparent mass to OWCs positioned offshore or on a breakwater. The authors concluded that the system response of an OWC fixed at the coastline depends more on the incident wave angle compared to that of offshore or breakwater cases. Gomes et al. [11] conducted a study to optimize the dimensions of a fixed OWC in a two degrees-of-freedom system using the linear wave theory. In the study, the authors stated that the dimensions of submerged and air-contained parts of the structure affect the annual power extraction. It was further revealed that the floating structure should be optimized for efficient conversion. Crema et al. [12] conducted experiments on a rectangular cross-section OWC (Figure 1a) using varied chamber sizes, drafts, and turbine damping before equipping a large floating structure with several OWCs. As it is hard to scale the turbine properties for the model experiments, turbines are represented by different sizes of orifices when the turbine damping effects are to be considered. A scaled model of the OWC was tested by Correia da Fonseca et al. [13] to determine the chamber air pressure, OWC motion in waves, and mooring line forces (Figure 1b). Henriques et al. [14] employed a systematic methodology including parameters of the geometry and the PTO system to design a wave energy converter. Elhanafi and Kim [15] experimentally tested a rectangular-shaped OWC with an orifice using regular waves with changing periods and heights and validated results by three-dimensional incompressible computational fluid dynamics (CFD) techniques. Although the effect of a single orifice was frequently studied in the literature, Elhanafi et al. [16] examined how the energy conversion would be affected in the case of two orifices. As a result of the study in which different orifice diameters were also examined numerically, the energy conversion increased significantly when multiple orifices were used. The scale effect on the air-water interaction in the OWC was investigated by Viviano et al. [17] by comparing small-scale models with two different chamber heights to a previously tested large-scale model. The authors found that the similarity of the wave height inside the OWC is greater between the large-scale model and the high-chamber small-scale model. Çelik and Altunkaynak [18] performed a series of experiments with varying chamber openings and turbine-induced damping of a rectangular OWC. Optimum data were presented by establishing a relation between the incoming wave characteristics and the orifice opening. Another fixed and rectangular cross-section OWC was investigated experimentally by Zabihi et al. [19], considering the sloshing effect in addition to the generally investigated parameters. Effects of sloped and perpendicular walls in an onshore OWC (Figure 1c) were numerically studied by Gaspar et al. [20]. Jalón and Brennan [21] inspected hydrodynamic performance and structural endurance of a bottom fixed OWC, which can be adapted to consecutive sea states. Their results revealed that in addition to providing ideal hydrodynamic efficiency, an adaptive system allows less cumulative fatigue damage. Moreover, the rotation speed of the turbine and the draft of the OWC are the essential variables regarding hydrodynamic efficiency. The physical modeling of an OWC in experiments leads to constraints that allow the effect of air compression to be neglected. Thus, López et al. [22] focused on the air volume scaling in the OWC. Findings of compressible and incompressible setups showed that air compressibility is an important factor in OWC efficiency. Since the OWC can be designed in different cross sections as well as integrated with floating breakwater, Howe et al. [23] experimentally examined the effect of incoming wave characteristics in different device configurations. Ning et al. [24] experimentally investigated the efficiency of a dual-chamber OWC by considering the effects of wave steepness, opening ratio, and internal and

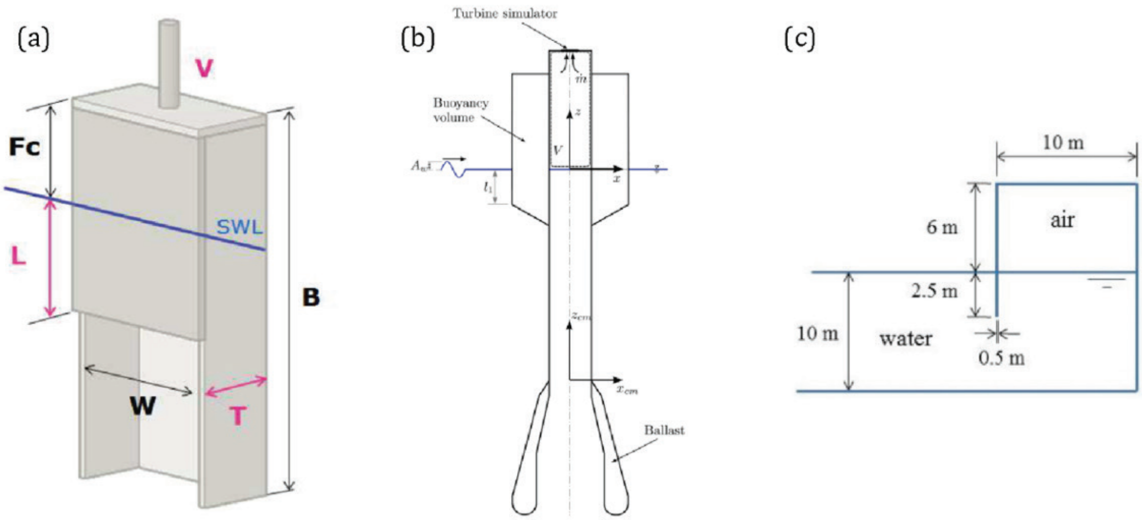

Figure 1. Sketches for different types of OWC devices in the literature: (a) rectangular cross-section OWC [12], (b) spar-buoy wave energy converter [13], (c) onshore type OWC [20]

OWC: Oscillating water column

external drafts. The hydrodynamic performance of the OWC was recently investigated by considering the novel designs with dual chambers [25-28].

OWC systems share a wide range of basic working principles with other wave energy generators and create a basis for understanding those principles. Motivations of this study can be listed as (1) comprehending the working principles of basic OWC systems and (2) understanding the effects of various parameters, i.e., draft and wave frequency, on the OWC internal motion. Therefore, the internal motion height in the cylinder representing a fixed OWC system was explored under regular wave conditions for three drafts (0.25, 0.40, and 0.55 m) and different wave frequencies ranging between 0.4 Hz and 1.2 Hz.

2. Experimental Investigation

Experiments were performed in the Ata Nutku Ship Model Testing Laboratory of İstanbul Technical University (ITU). The OWC model was mounted on a towing carriage with a support rod to prevent the cylinder motion as can be seen in Figure 2. Mounting the cylinder to a vertical position adjuster facilitated draft modification processes without disassembling the cylinder from the towing tank. A comparison of the water level inside the cylinder to the wave height is directly relative to the power output of the OWCs. Therefore, the change in the water level inside the cylinder was measured. Two of the SICK DT35 laser distance sensors were located at the top of the cylinder to measure the change of the water level. Laser sensors were

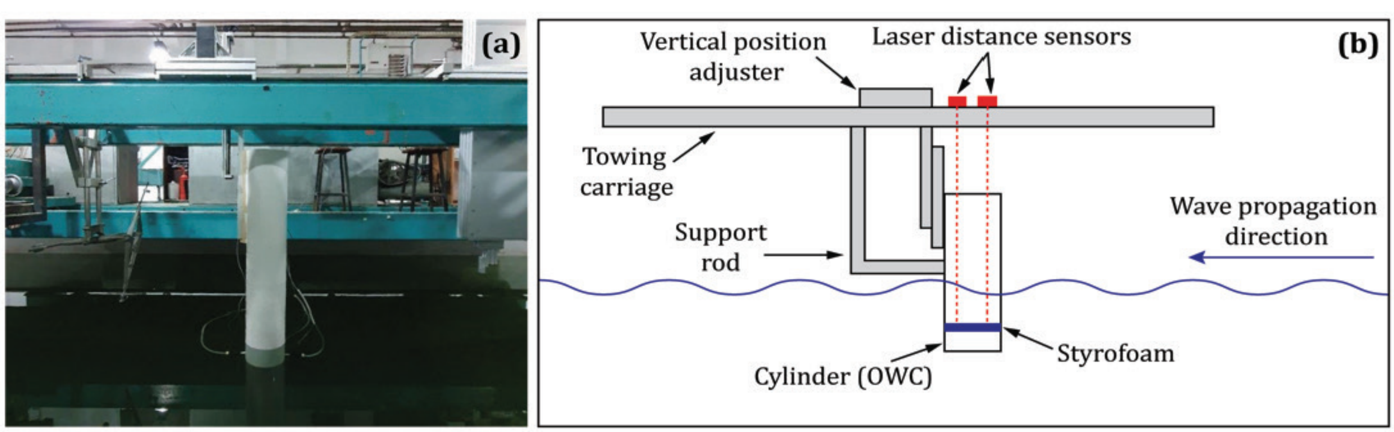

Figure 2. (a) Experimental setup of the OWC, (b) schematic diagram with laser distance sensor positions

OWC: Oscillating water column

calibrated and tested for their accuracy beforehand. As a target, a reflective and fully buoyant styrofoam that moves depending on water level changes was located inside the cylinder. A commercial data logger and its respective data acquisition software were used to collect data from laser distance sensors. An appropriate low pass filter built into the data acquisition system was employed for each case to filter out the noise in the gathered data. Additionally, a sampling rate higher than the Nyquist rate was set for the sensors to avoid aliasing.

Two reasons for choosing a fixed OWC structure include (1) the robustness and safety of fixed devices under all sea conditions (with the disadvantage of having a low efficiency) and (2) being free of variables, a floating OWC device would introduce through different kinds of mooring options. With these, obtaining a clearer view of the effects of draft and wave frequency variation was possible.

The outer diameter of the OWC model is 0.25 m. The model has a wall thickness of 4.9 mm and an inner diameter of 0.24 m. The total length of the model was set to 1.50 m to adjust the freeboard of the model with a changing draft. The draft effect on the water level inside the OWC was carried out by changing the draft. Tested drafts (*d*) are 0.25 m, 0.40 m, and 0.55 m. The selected material of the OWC model is polyvinyl chloride due to the availability of desired dimensions and formability capabilities of the material. Distance markers were placed on the OWC surface to visualize the wave height and practical draft change.

The effect of the wave frequency on the water level inside the OWC was also tested with changing wave frequencies of 0.4, 0.5, 0.6, 0.8, 0.9, 1.0, and 1.2 Hz at each draft. Regular waves were generated with a constant height of 0.12 m in the towing tank. Note that the waves require damping before the next run. Otherwise, a regular wave formation may be disturbed because of the overlapping waves and decrease the accuracy of the measurement.

3. Numerical Modeling

3.1. Physics Modeling

The standard *k-ε* turbulence model was preferred among a variety of turbulence models to solve the closure problem. Spatial discretization of convective terms in Reynolds-averaged Navier-Stokes equations was performed with the 2nd order solution scheme. The free surface forming the interface between water and air was determined using the volume-of-fluid method (VOF) in numerical analyses. The method works by calculating the part of the light (air) and heavy (water) fluid in each cell in multiphase cases. Accurately established free-surface simulations also show that water and air particles are separated by a sharp interface. Therefore, the VOF method was applied by the high-resolution interface-capturing scheme to get a numerical diffusion or dispersion error at a level that does not affect the solution. Second-order temporal discretization was performed in all computations because a false diffusion effect could occur at the water-air interface and the damping effect on the wave height would be dominant if the first-order discretization was preferred. In this study, hydrodynamic analysis of a fixed-type OWC was carried out by CFD methods with the commercial CFD code Siemens PLM STAR-CCM+.

3.2. Computational Domain and Boundary Conditions

To solve the physical problem numerically, a computational domain needs to be correctly selected. Boundaries of the computational domain should be sufficiently far from the region where solution accuracy is critical, and the computational cost should also be considered. The fact that the distance of the inlet, outlet, and lateral surfaces to any geometry is too small may adversely affect the numerical results. Generally, the flow with a high amount of irregularity near the outlet boundary and the outlet boundary with a uniform pressure definition lead to this problem. It can be said that the outlet boundary is very close to the geometry that causes irregular flow. To avoid this problem, the outlet should be positioned at a distance where the flow takes a regular form before it reaches the boundary. For a cylinder diameter D, dimensions of the computational domain are determined from the center of the cylinder as can be seen in Figure 3. The computational domains were created for each wave condition. It should be also noted that analyses were carried out with a half model to investigate the oscillating flow inside the OWC structure.

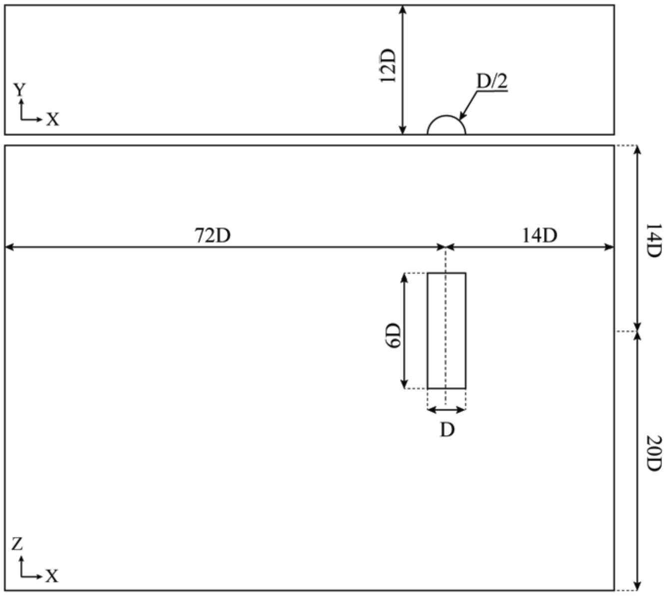

Figure 3. *Dimensions of the numerical wave tank*

Figure 4 illustrates the boundary conditions for the numerical setup for a fixed-type OWC. The positive *x*-direction, which is the direction of the generation of the regular wave during the analysis, and the top boundary were modeled as velocity inlets. The symmetry condition is applied to the symmetry plane and the side of the domain to avoid reflection. The plane behind the cylinder was set as the pressure outlet boundary condition to prevent backflow. The boundary condition of the cylinder and the bottom of the domain were selected as the no-slip wall.

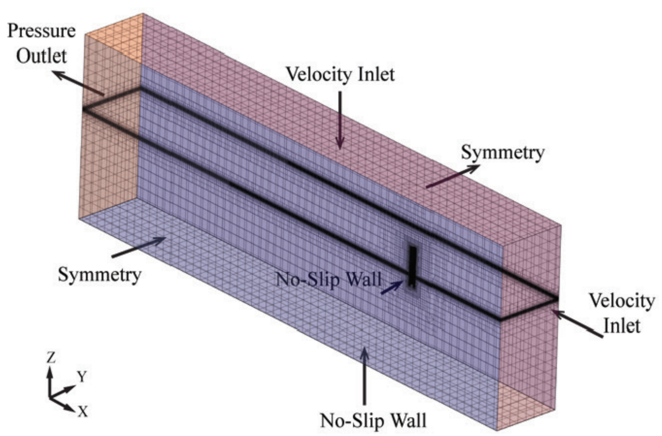

Figure 4. *Boundary conditions of numerical wave tank*

3.3. Mesh Generation

The grid structure should be generated according to certain rules to avoid distortion of the free surface layer as the wave travels [29]. It is known that the wave height is constant and if the wave steepness ratio (H/λ, where H is the wave height and λ is the wavelength) is greater than 1/7 (critical wave steepness ratio), then the wave is considered to be very steep. However, under present conditions, the preferred waveforms are quite far from becoming a steep wave. Thus, refinement in the direction of the wave height (*+z*) was kept constant and refinement in the *x*-axis was changed by changing the wavelength. Various studies in the literature that can be used as a guide for creating a successful phase separation for the free surface problem. CD-Adapco recommends 80-100 and 20 cells per wavelength and per wave amplitude respectively [30], while the International Towing Tank Conference guideline recommends 10 to 40 cells [31]. 20 cells for each wave amplitude in the *z*-axis and 80 cells for the *x*-axis for each wavelength were preferred in the mesh generation. Figure 5 illustrates the mesh generation and volume fraction of the free surface for the case of d=0.40 m and f_w=1.0 Hz, where d is the draft and f_w is the wave frequency. As a result, between 2 million and 3.5 million cells were used in total. A grid independence study was not performed in the study. Mesh combinations proposed in the literature proved to provide convincing outcomes [6]. The main solution parameters in Table 1 were used in numerical computations.

Table 1. *Solution parameters*

Parameter	Value
Grid number	2.5-3 M
Maximum inner iteration	5
Time step	0.004-0.013 s
Solution time	25 s
Elapsed time	~8.1 h
Convergence criteria	10E-3

3.4. Wave Modeling

The first-order VOF wave used in numerical simulations was modeled to have a regular periodic sinusoidal profile. The elevation of the free surface is defined as (formula 1 is below):

$$\eta(x,t) = A\cos(kx - \omega t), \quad (1)$$

where A is the wave amplitude, ω is the wave frequency, k is the wave number, k = 2π/λ, *t* is the time, and λ is the

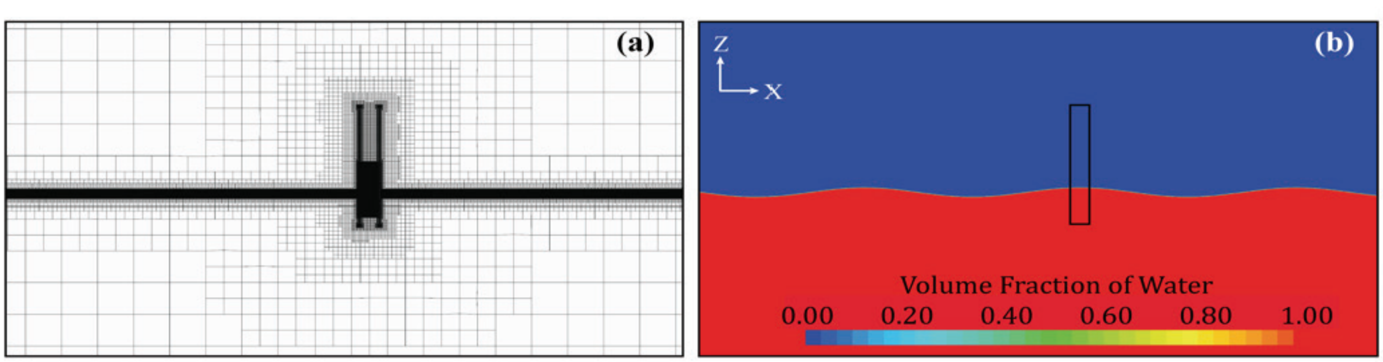

Figure 5. *Numerical wave tank (d=0.40 m, fw=1.0 Hz): (a) mesh generation of the xz plane, (b) volume fraction of water*

wavelength. The dispersion relation, between the wave period, T_w, and the wavelength, λ, for first-order waves in finite water is (formula 2 is below):

$$\omega^2 = gk \tanh kh \quad (2)$$

The deepwater wave assumption was considered to calculate the wave frequencies. According to the deepwater assumption, the water depth should be greater than half of the wavelength. In the study conducted at a constant wave height, regular wave frequencies ranged between 0.4 Hz and 1.2 Hz. Table 2 gives the wave parameters preferred in numerical calculations. The time step was also determined according to the wave periods, T_w, and the refinement number for cells per wavelength, n (formula 3 is below):

$$\Delta t = \frac{T_w}{n \times 2.4} \quad (3)$$

Wave reflection directly affects the results in both experimental and numerical wave tanks. It is important that forcing or damping conditions at the boundaries are appropriately applied in VOF modeling. By this means, wave oscillations and reflections can be reduced around the boundaries. While various damping/forcing methods can be applied on a numerical wave tank [32] the effects of these methods were not extensively studied in the present study. Instead, the damping length, x_d, was selected to be equal to the wavelength from the outlet boundary to the positive x-direction. It can be noted that only small reflections are visible at x_d=λ where the damping length is equal to the wavelength.

4. Results

Figure 6 illustrates the final results from the experiments, numerical simulations, and analytical solutions in terms of wave frequency-response amplitude operator (RAO) relations. The change in the water level inside the OWC is calculated as the mean of the peak-to-peak value of the oscillations inside the cylinder for all methods. Numerical and experimental outcomes for the water level inside

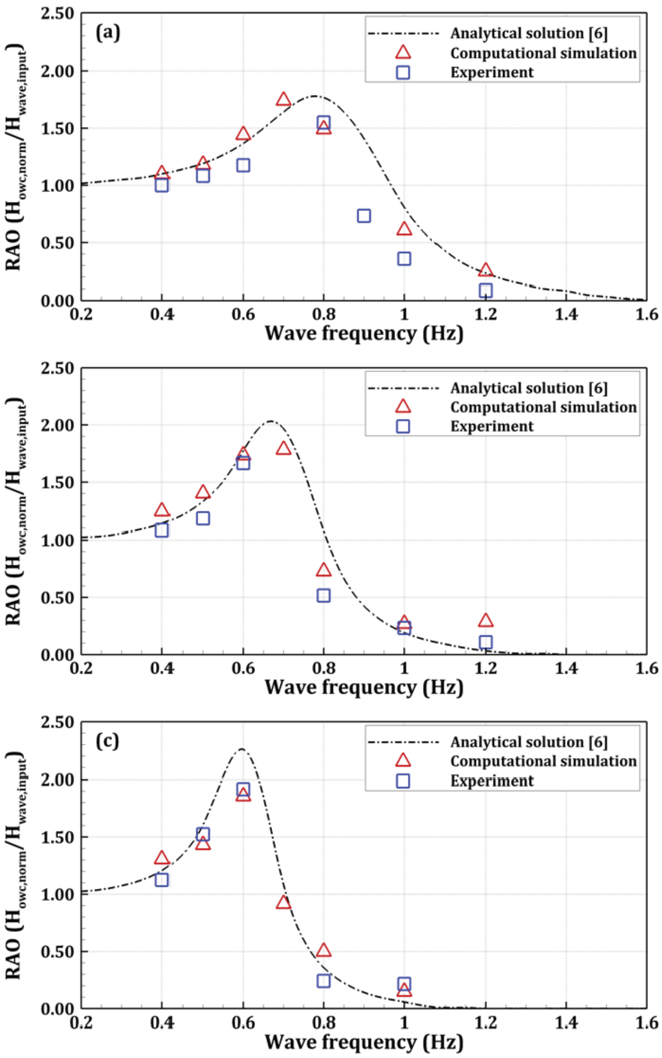

Figure 6. Non-dimensionalized internal motion comparison for (a) d=0.25 m, (b) d=0.40 m, and (c) d=0.55 m

RAO: Response amplitude operator

Table 2. Regular wave parameters

Wave height	Wave length	Wave period	Wave frequency	Wave steepness	Damping length
$H_{wave,input}$	λ	T_w	f_w	ε	x_d
m	m	s	Hz	-	m
0.12	9.50	2.50	0.40	0.01	9.50
	6.24	2.00	0.50	0.02	6.24
	4.34	1.67	0.60	0.03	4.34
	2.44	1.25	0.80	0.05	2.44
	1.27	1.11	0.90	0.09	1.27
	1.56	1.00	1.00	0.08	1.56
	1.08	0.83	1.20	0.11	1.08

the OWC (H_{owc}) were compared to each other in a non-dimensionalized form. The obtained water level inside the OWC is normalized as follows (formula 4 is below):

$$H_{owc,norm} = \frac{H_{owc}}{H_{wave,out}} \times H_{wave,input} \quad (4)$$

The RAO of the water level inside the OWC is calculated by the following equation (formula 5 is below):

$$RAO = \frac{H_{owc,norm}}{H_{wave,input}} \quad (5)$$

Analytical results were derived using concepts and equations presented in the study of McCormick [6]. To attain an understanding of the overall performance of the more complicated OWC, one must first understand the nature of the free-surface motions of a simple orifice system. To fully analyze the free-surface motion within the OWC, the compressibility of the air and the viscosity of the flow must be taken into account. However, the compared analytical method did not take into account some of these physical conditions to simplify the problem. It is assumed that the air is incompressible and a loss term is used to represent the viscosity. Moreover, due to experimental limitations, the motion of the OWC and the mooring systems were not included in the experimental setup. These constraints align with the approach of the analytical solution.

The trends observed in the analytical solutions for all drafts are consistent with numerical and experimental results. The results can be detailed as follows.

- Due to viscous effects, the results obtained from the experimental and numerical solutions are observed to be lower around the peak frequency than the analytical results. A successful match was achieved at low and high frequencies.

- The maximum water level change is observed to increase as the draft increases and the frequency at which this value is observed (natural frequency) decreases.

- Maximum RAO values obtained from the experiments and numerical solutions were found to be compatible. The peak value was around 0.8 Hz, 0.7 Hz, and 0.6 Hz for d=0.25 m, d=0.40 m, and d=0.55 m, respectively.

- The RAO value used in the results can be expressed as the ratio of the amplitude of the water motion in the OWC to the incoming wave amplitude. For RAO values greater than 1, the change in the water height in the OWC is greater than the incoming wave height.

5. Conclusion

In this study, the internal motion height in the cylinder representing a fixed OWC system was investigated to understand the effects of important parameters such as the draft and wave frequency on the system. Therefore, systematic experiments were carried out using the towing tank and wave-making device in the Ata Nutku Ship Model Testing Laboratory of ITU under three different drafts and different wave frequencies in regular waves. Numerical simulations and analytical calculations were also conducted to compare and support the experimental results.

The findings reveal that increasing the draft of an OWC also increases the general performance of the system. Conversely, variation in the OWC draft creates a change in the optimal wave frequency of the system and thus may decrease the efficiency of the converter for a specific operation site.

Even though a correlation between the draft value and the performance of the OWC was achieved, it may not be possible to estimate how this trend would continue due to a limited number of drafts tested in the experiments. There can be a point in the draft values for which the increase in the RAO plateaus or drops back. Therefore, further studies can be performed with a wider draft range to determine the behavior.

This study should also be extended to incorporate the orifice diameter and the turbine effect, as these will also have a notable effect on energy conversion. With the present cylinder and suitable mooring methods used to represent its oscillation, a future study on the changes in the energy output could be made. Also, a precise pressure sensor will increase the accuracy of the data, and comparison with the laser distance sensor will increase the precision.

Authorship Contributions

Concept design: D. Öztürk, M.O. Şerifoğlu, Data Collection or Processing: D. Öztürk, M.O. Şerifoğlu, Analysis or Interpretation: D. Öztürk, M.O. Şerifoğlu, Literature Review: D. Öztürk, M.O. Şerifoğlu, Writing, Reviewing and Editing: D. Öztürk, M.O. Şerifoğlu.

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The Coupling Effect on Torsional and Longitudinal Vibrations of Marine Propulsion Shaft System

Akile Neşe Halilbeşe[1], Osman Azmi Özsoysal[2]

[1]Ordu University, Department of Marine Engineering, Ordu, Turkey
[2]İstanbul Technical University, Department of Naval Architecture and Marine Engineering, İstanbul, Turkey

Abstract

The propulsion shaft system is one of the essential parts of the ships due to its reliability and stabilization directly affecting the safety in operation. The propulsion system transmits the torque generated by the engine to the propeller via the main shaft. During its navigation, torsional, longitudinal, and transversal vibrations inevitably occur, and precautions must be taken during the design stage to prevent system damage and reduce power transmission efficiency. In this article, three dissimilar models numerically generated by the lumped-mass method are used to investigate the harmonic conclusions of forced coupled torsional and longitudinal vibrations of the system. Numerical results correlated with the experimental results at rotational speed and load acting onto the propulsion shaft system. A further finding is to create a third method upon discussing the facts revealed by analyzing the advantages and disadvantages of the models, especially considering differences between the first two models.

Keywords

Coupled torsional-longitudinal vibrations, Forced vibrations, Marine propulsion shaft system, Lumped-mass method

1. Introduction

The reliability of a cruising vessel is directly related to the safety of the propeller-shaft system. Ships are subjected to different forces during navigation, such as waves, wind, and other exciting forces [1]. These forces create extreme vibrations in torsional, longitudinal, and transverse modes and their coupled forms, resulting in an undesirable and intensified vibration response of the shaft [2]. Coupled vibrations would raise the noise level by stimulating the shafts and foundation, bearings, and hull. As a result, the poor performance of the system will lead to fatigue, fracture, and tribological problems on the shaft, and even failures for the overall shaft system. Consequently, the ship's navigation reliability will be significantly reduced [3].

The majority of the studies on the dynamic behavior of the propulsion system deals with the single-axis vibrations by ignoring the coupled vibrations, resulting in different results by the actual measurements [4,5]. Torsional vibration is the foremost dangerous type for the crankshaft, bearings, and shaft lining and is mostly studied in single-axis vibration investigations [6]. Huang and Horng [7] used the transfer matrix method for torsional vibration analysis of damped systems. Wu and Yang [8] studied free and forced torsional vibration problems for the multidegree of freedom system using the transfer matrix method. The finite element method was frequently applied for torsional vibration analysis [9-11]. Besides, some of these studies on torsional, longitudinal, and transverse vibration were evaluated by experiments [12,13]. Gan-boa and Yaoa [14] used the reduced-order modeling method to control the longitudinal vibration of a marine propulsion shaft system. Earlier research focused on separate torsional and longitudinal vibrations without interaction between them. It is observed that eliminating the interaction significantly distorts results for the measurements [15]. Huang et al. [16] also reported that only a few studies in the literature that focus on the coupled vibrations of propeller-shaft systems.

Address for Correspondence: Akile Neşe Halilbeşe, Ordu University, Department of Marine Engineering, Ordu, Turkey
E-mail: akile.nese@gmail.com
ORCID ID: orcid.org/0000-0002-8182-4364

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Parsons [17] first showed the coupled torsional and longitudinal vibrations of propeller-shaft systems, considering the coupling through added mass and hydrodynamic damping coefficients due to the propeller. The Ritz method and Lagrange equation, as well as Hamilton's principle discretized by the Galerkin method, are used to investigate coupled longitudinal-transverse vibrations of a propulsion shaft system [18,19]. Using the lumped-mass method, Huang et al. [16] studied the coupled torsional-longitudinal problem experimentally and numerically. Unlike the studies that considered the coupling through added mass and hydrodynamic damping coefficients, they examined the system's response by considering the coupling through a stiffness matrix using specific values to this coefficient. Moreover, the longitudinal vibration of the system was predicted by ignoring the bearings, and a different path was considered by splitting the shaft into masses compared to other publications on this topic.

In this study, the first model proposed by Huang et al. [16] and the second model obtained the coupling effect from the propeller are compared for the coupled torsional-longitudinal vibrations of a propeller-shaft system. To more accurately observe the effect of differences between Model 1 and Model 2 on the coupled vibrations, a new model, Model 3, is formed by utilizing these differences. Experimental verifications are also provided for those three models. The lumped-mass method is adopted for both coupled and uncoupled torsional-longitudinal vibration. The response amplitudes due to harmonic loadings are presented to observe the effect of coupling.

2. Methodology and Numerical Model

In this study, the coupled torsional-longitudinal vibrations of a propeller-shaft system are numerically studied using the lumped-mass method and adopting the approaches described as Model 1 and Model 2, respectively. After evaluating the differences between these two models, a new analysis model was decided, and Model 3 was formed.

The shaft can be modeled as an Euler beam with a mass payload, equivalent to a cantilever beam with its mass center away from the centerline [20,21]. The shaft is modeled using the Euler beam, with the engine as the fixed end and the propeller as the free end [16,22]. Figure 1 presents the installation diagram, consisting of four different parts. The gravity center of the attached mass, i.e., propeller, may not coincide with its attachment point to the beam. This beam can generally be subjected to torsional and longitudinal deformations due to the acting forces [16,23].

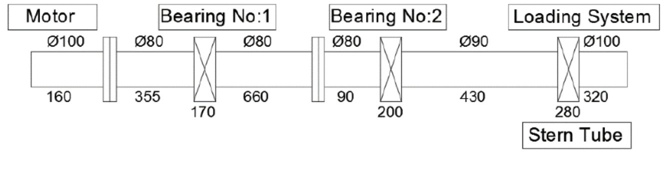

Figure 1. *Details of the shaft system*

When the propeller starts to rotate and then experiences longitudinal or torsional vibrations, it will develop an oscillatory lift that produces both an axial force and a torque motion [17]. Considering the uncoupled torsional and longitudinal vibrations, the equation of motion of the shaft system, in the discretized form, can be given as (Equation 1 is below):

$$\begin{aligned} \boldsymbol{J}\ddot{\theta} + \boldsymbol{D}_t\dot{\theta} + \boldsymbol{K}_t\theta &= T\sin(\omega t) \\ \boldsymbol{M}\ddot{x} + \boldsymbol{D}_x\dot{x} + \boldsymbol{K}_x x &= F\sin(\omega t) \end{aligned} \quad (1)$$

Here, $\boldsymbol{M}$ is the mass matrix; $\boldsymbol{J}$ is the moment of inertia; $\boldsymbol{K}_t$ and $\boldsymbol{K}_x$ represent the torsional stiffness and longitudinal stiffness, respectively; $\boldsymbol{D}_t$ and $\boldsymbol{D}_x$ represent the torsional damping and longitudinal damping, respectively; T and F represent the amplitudes of the torque and axial force induced by the propeller, respectively; $\boldsymbol{\theta}$ and $\boldsymbol{x}$ denote the torsional angle and axial displacement, respectively; w is the excitation frequency. Since there is no thrust bearing in the experimental setup, the entire shaft system is modeled for calculating longitudinal vibrations. Figure 2 shows the experimental setup, including disks attached to the shaft instead of crankshafts. While there is no combustion in the experimental setup, the torque caused by the gas pressure does not exist. Besides, the inertia and torque of the disks are quite small compared to the shaft; consequently, disks are not included in the numerical model.

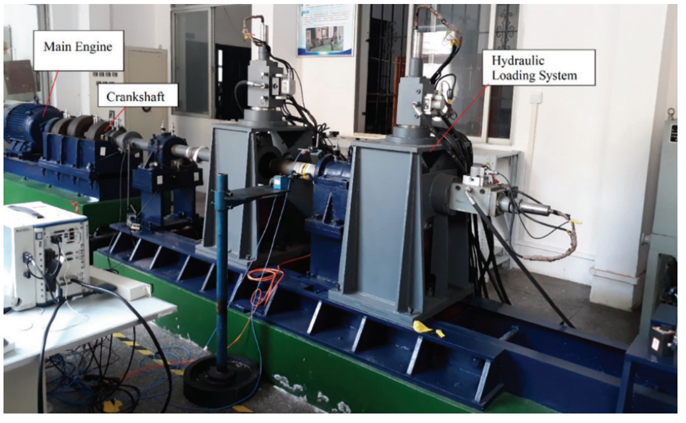

Figure 2. *Experimental setup of the propulsion shaft system*

The equation of the motion of the marine propulsion shaft system is shown for the undamped and unforced system with Equation 2 to define the coupling effect. When the propeller rotates and vibrates either longitudinally or torsionally, it will develop an oscillatory lift that will produce both an oscillatory axial force and oscillatory torque on the propeller. These components will provide the coupled longitudinal and torsional motion. Neglecting the damping that occurred on the system, the hydrodynamic force and moment proportional to the acceleration will produce the following coupled equations of motion [17];

For the four sectioned shaft system, the moment of inertia and mass matrices are given as follows:

$$J=\begin{bmatrix} J_1 & 0 & 0 & 0 \\ 0 & J_2 & 0 & 0 \\ 0 & 0 & J_3 & 0 \\ 0 & 0 & 0 & J_4 \end{bmatrix}, M=\begin{bmatrix} m_1 & 0 & 0 & 0 \\ 0 & m_2 & 0 & 0 \\ 0 & 0 & m_3 & 0 \\ 0 & 0 & 0 & m_4 \end{bmatrix}, \tag{2}$$

the torsional damping and longitudinal damping matrices are defined as follows:

$$D_t=\begin{bmatrix} d_{t_1} & -d_{t_1} & 0 & 0 \\ -d_{t_1} & d_{t_1}+d_{t_2} & -d_{t_2} & 0 \\ 0 & -d_{t_2} & d_{t_2}+d_{t_3} & -d_{t_3} \\ 0 & 0 & -d_{t_3} & d_{t_3} \end{bmatrix} \tag{3a}$$

$$D_x=\begin{bmatrix} d_{x_1} & -d_{x_1} & 0 & 0 \\ -d_{x_1} & d_{x_1}+d_{x_2} & -d_{x_2} & 0 \\ 0 & -d_{x_2} & d_{x_2}+d_{x_3} & -d_{x_3} \\ 0 & 0 & -d_{x_3} & d_{x_3} \end{bmatrix} \tag{3b}$$

and the torsional stiffness matrix is defined as follows:

$$K_t=\begin{bmatrix} k_{t_1} & -k_{t_1} & 0 & 0 \\ -k_{t_1} & k_{t_1}+k_{t_2} & -k_{t_2} & 0 \\ 0 & -k_{t_2} & k_{t_2}+k_{t_3} & -k_{t_3} \\ 0 & 0 & -k_{t_3} & k_{t_3} \end{bmatrix} \tag{4}$$

Here, the coefficients d_{t_j} and d_{x_j}, defining the torsional and longitudinal damping for the jth shaft, are given by $d_{t_j} = 0.08 J_j \omega_j$, $d_{x_j} = 0.05 m_j \omega_j$, respectively, and the coefficients k_{t_j} defining the torsional stiffness is given by $k_{t_j} = GJ_j/L_j$ in which L_j is the length of the jth section [16]. Since the longitudinal stiffness depends on the selected solution model, it can be presented as follows:

The external forcing in Equation (1) can be defined as

$$T=\begin{bmatrix} T_t & 0 & 0 & 0 \end{bmatrix} \; F=\begin{bmatrix} F_x & 0 & 0 & 0 \end{bmatrix} \tag{5}$$

and the response of the system is represented as follows:

$$\theta=\begin{bmatrix} \theta_1 & \theta_2 & \theta_3 & \theta_4 \end{bmatrix} \; x=\begin{bmatrix} x_1 & x_2 & x_3 & x_4 \end{bmatrix} \tag{6}$$

The proposed solution models for the coupled torsional-longitudinal vibration of the propeller-shaft system differ from each other depending on the adopted coupling mechanism, as briefly discussed next.

Model 1

The coupled vibrations of the system are described as [21] follows:

$$\begin{bmatrix} M & 0 \\ 0 & J \end{bmatrix}\begin{bmatrix} \ddot{x} \\ \ddot{\theta} \end{bmatrix}+\begin{bmatrix} D_x & 0 \\ 0 & D_t \end{bmatrix}\begin{bmatrix} \dot{x} \\ \dot{\theta} \end{bmatrix}+\begin{bmatrix} K_x & -K_{xt} \\ -K_{tx} & K_t \end{bmatrix}\begin{bmatrix} x \\ \theta \end{bmatrix}=\begin{bmatrix} F \\ T \end{bmatrix} \tag{7}$$

Here, the longitudinal stiffness is given by

$$K_x=\begin{bmatrix} k_{x_1} & -k_{x_1} & 0 & 0 \\ -k_{x_1} & k_{x_1}+k_{x_2} & -k_{x_2} & 0 \\ 0 & -k_{x_2} & k_{x_2}+k_{x_3} & -k_{x_3} \\ 0 & 0 & -k_{x_3} & k_{x_3}+k_{x_4} \end{bmatrix} \tag{8}$$

Where $k_{x_j} = EA/L_j$; the coupling between axial and rotational motions is introduced through the diagonal stiffness matrices K_{tx}, K_{xt}, which are defined by $k_{xt_j} = \delta k_t$, $k_{tx_j} = \delta k_{x_j}$.

The equation of the motion for the free vibrations of the marine propulsion shaft system can be given to define the coupling effect, as follows:

$$\begin{bmatrix} m & m_c \\ m_c & J \end{bmatrix}\begin{bmatrix} \ddot{x} \\ \ddot{\theta} \end{bmatrix}+\begin{bmatrix} k_x & 0 \\ 0 & k_t \end{bmatrix}\begin{bmatrix} x \\ \theta \end{bmatrix}=0 \tag{9}$$

Here, m_c introduces inertial coupling depending on the propeller characteristics. Using the solutions $x=ReX\,e^{i\omega t}$ and $\theta=Re\Theta\,e^{i\omega t}$ in Equation (2), the following eigenvalue problem is obtained:

$$\begin{bmatrix} \left(k_x - m\omega^2\right) & -m_c\omega^2 \\ -m_c\omega^2 & \left(k_\theta - J\omega^2\right) \end{bmatrix}\begin{bmatrix} x \\ \theta \end{bmatrix}=0 \tag{10}$$

By defining $\omega_x=\sqrt{k_x/m}$ and $\omega_t=\sqrt{k_t/m}$, the characteristic equation for Equation (4) can be given as follows:

$$\omega^4\left(1-\delta\right)-\omega^2\left(\omega_t^{\,2}+\omega_x^{\,2}\right)+\omega_x^{\,2}\omega_t^{\,2}=0 \tag{11}$$

Here the coupling coefficient δ, which describes the longitudinal deformation induced by the torsional angle, is defined as

$$\delta=\frac{m_c^{\,2}}{mJ} \tag{12}$$

Due to a lack of propeller in the experimental setup, this study adopts 0.02 value from the literature [17,20].

Model 2

In Model 2, each shaft is divided into two masses for longitudinal vibration, and the moment of inertia of the shaft is neglected considering that it is relatively small compared to the corresponding values of the propeller and gears, including two components that are omitted in Model 1. For presenting a well-suited assessment of the models compared with the test results in Section 4, each shaft is modeled as a mass, and moments of inertia of the shafts are inevitably taken into account as the test system involves no propeller or gears. Unlike Model 1, the torsional and longitudinal vibrations are coupled due to the radiated flow from the propeller in Model 2, and the interaction terms are given in terms of fluid added mass (M_c), hydrodynamic damping (D_c) and hydrodynamic stiffness (K_c). The equation of motion of the shaft system is as follows:

$$\begin{bmatrix} M & M_c^T \\ M_c & J \end{bmatrix}\begin{bmatrix} \ddot{x} \\ \ddot{\theta} \end{bmatrix}+\begin{bmatrix} D_x & D_c^T \\ D_c & D_t \end{bmatrix}\begin{bmatrix} \dot{x} \\ \dot{\theta} \end{bmatrix}+\begin{bmatrix} K_x & K_c^T \\ K_c & K_t \end{bmatrix}\begin{bmatrix} x \\ \theta \end{bmatrix}=\begin{bmatrix} F \\ T \end{bmatrix} \quad (13)$$

Hence, the interaction terms for the system given in Figure 1 are zero due to the lack of propeller; the resulting equation of motion describing the uncoupled vibrations of the propeller-shaft system can be defined as follows:

$$\begin{bmatrix} M & 0 \\ 0 & J \end{bmatrix}\begin{bmatrix} \ddot{x} \\ \ddot{\theta} \end{bmatrix}+\begin{bmatrix} D_x & 0 \\ 0 & D_t \end{bmatrix}\begin{bmatrix} \dot{x} \\ \dot{\theta} \end{bmatrix}+\begin{bmatrix} K_x & 0 \\ 0 & K_t \end{bmatrix}\begin{bmatrix} x \\ \theta \end{bmatrix}=\begin{bmatrix} F \\ T \end{bmatrix} \quad (14)$$

Since bearings are allowed in the system and coupling has no stiffness component, the longitudinal stiffness matrix is different from Model 1 as follows:

$$K_x=\begin{bmatrix} k_{x_1} & -k_{x_1} & 0 & 0 \\ -k_{x_1} & k_{x_1}+k_{x_2}+k_{x_5} & -k_{x_2} & 0 \\ 0 & -k_{x_2} & k_{x_2}+k_{x_3}+k_{x_6} & -k_{x_3} \\ 0 & 0 & -k_{x_3} & k_{x_3}+k_{x_4}+k_{x_7} \end{bmatrix} \quad (15)$$

Here, $k_{x_j} = EA/L_j$; $k_{x_5}, k_{x_6}, k_{x_7}$ represent the stiffness of the bearings, considering that they are attached to the foundation, which is attached to the ground, and their values are considered as 1.0 GN/m [24,25]. Figure 1 shows the location of the bearings, which are included in the mass elastic system from the connection points.

Model 3

Model 3 is formed by collecting the coupling mechanism inherent to Model 1 and the bearing mechanism in Model 2 to provide more realistic predictions of the coupled dynamic behavior of the propeller-shaft system-it involves inertia, damping, and stiffness coupling terms. The coupled torsional-longitudinal vibrations of the system are now defined by

$$\begin{bmatrix} M & 0 \\ 0 & J \end{bmatrix}\begin{bmatrix} \ddot{x} \\ \ddot{\theta} \end{bmatrix}+\begin{bmatrix} D_x & 0 \\ 0 & D_t \end{bmatrix}\begin{bmatrix} \dot{x} \\ \dot{\theta} \end{bmatrix}+\begin{bmatrix} K_x & -K_{xt} \\ -K_{tx} & K_t \end{bmatrix}\begin{bmatrix} x \\ \theta \end{bmatrix}=\begin{bmatrix} F \\ T \end{bmatrix} \quad (16)$$

All entities in Equation (16) are previously defined; the mass moment of inertia matrix (*J*) and mass matrix (*M*) are given in Equation (6). The torsional and longitudinal stiffness matrices of the system are given in Equation (8), and Equation (15) whereas torsional and longitudinal damping matrices are given as Equation (7a) and Equation (7b). The stiffness matrices K_{tx} and K_{xt} are defined by $\delta \times K_x, K_t$.

3. Experimental Setup

The coupled torsional-longitudinal vibration of the shaft system is also experimentally investigated to verify the numerical predictions. The general view of the test bed and its installation are shown in Figure 2. The experimental setup consists of an actuator that represents the propeller connected to the end of the shaft, a bearing for preventing hogging or sagging of the unsupported span of the shaft, a drive unit acting as a marine engine at the other end of the shaft, a foundation for mounting the whole plants, and a base frequency converter.

The propulsion shaft system consists of two intermediate shafts and a tail shaft. The shafts are connected using a hydraulic coupling. Two intermediate bearings support the intermediate shafts, and another stern bearing supports the tail shaft [5]. Theoretical material properties are considered as E=206 GPa, G=77 GPa, and p=7850 kg/m^3. Table 1 presents the geometrical properties of each shaft segment, where the order is from the fixed end (engine side) to the free end (propeller side). Figure 3 shows measurement points by locating the sensors transmitting the analog signals.

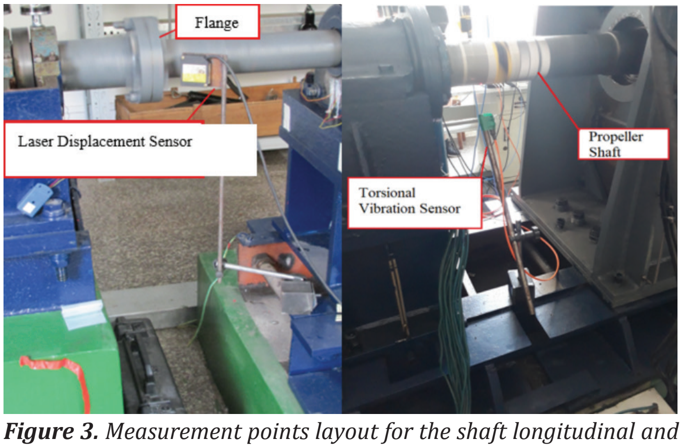

Figure 3. *Measurement points layout for the shaft longitudinal and torsional vibrations*

Table 1. *Geometrical properties of the shaft segments*

Shaft no	1	2	3	4
Length (m)	0.6	0.935	0.67	0.46
Diameters (m)	0.08	0.08	0.09	0.1

Both torsional and longitudinal vibration signals are recorded simultaneously along the shaft. Signals were recorded at 0.0005 s intervals for 1 min. The laser torsional vibration meter (B&K MM0071 sensor and 2523 laser) is used to measure the signal of the tail shaft and to check and compare with the shaft speed, as shown in Figure 4. The laser's measurement frequency range is 0.5 to 3000 Hz, and its sensitivity is 100 mV/g. The flange surface at the intermediate shaft is selected for measuring the longitudinal vibration, where the laser displacement sensor (OPTEX CD33) is used. The sensor position is fixed to reduce possible errors due to the vibration. Longitudinal loads are adjusted using a hydraulic system. Repeat accuracy is also 2 μm*, and high-accuracy displacement measurement is supported. The torque generated by the longitudinal force is measured using a strain gage placed on the intermediate shaft. Shaft speed is increased from 100 rpm to 190 rpm with an interval of 30 rpm, and displacement amplitudes for the shaft coupled vibrations are recorded for each speed. However, the measurements and results presented in Section 4 are only for 100 rpm. The amplitudes of the applied axial force and corresponding torque are 0.055 Nm and 86 kN, respectively, for 100 rpm. Since the test apparatus allows only axial and transversal loadings, the torsional stress could not be obtained directly, yet torque values are acquired from the measured longitudinal stresses. The longitudinal stresses are collected for the axial forces applied in terms of the displacements of the loading system. Table 2 presents applied displacements, measured torque, and axial force amplitudes.

Table 2. *Torque and axial force values for the considered rotational speeds*

Rotational speed (rpm)	100	130	160	190
Displacement (mm)	0.6	0.9	1.2	1.5
Axial force (kN)	85.904	87.129	88.359	89.586
Torque (Nm)	0.055	0.125	0.275	0.325

4. Application and Discussion

For achieving stable results, simulation time is taken as 10 seconds. The initial conditions are applied as $\theta_j = x_j = \dot{\theta}_j = \dot{x}_j = 0$. The unknown coupling stiffness coefficients are assumed to be $k_{tx} = k_{xt} = 0$.

4.1. Verification

Figure 5 and 6 indicate the axial displacement and torsional angle values obtained from all numerical models and experiments at 100-190 rpm shaft speed. The hydrodynamic effect is presented using the coupling stiffness coefficient in Method 1 [17]. The bearings are considered, and the coupled

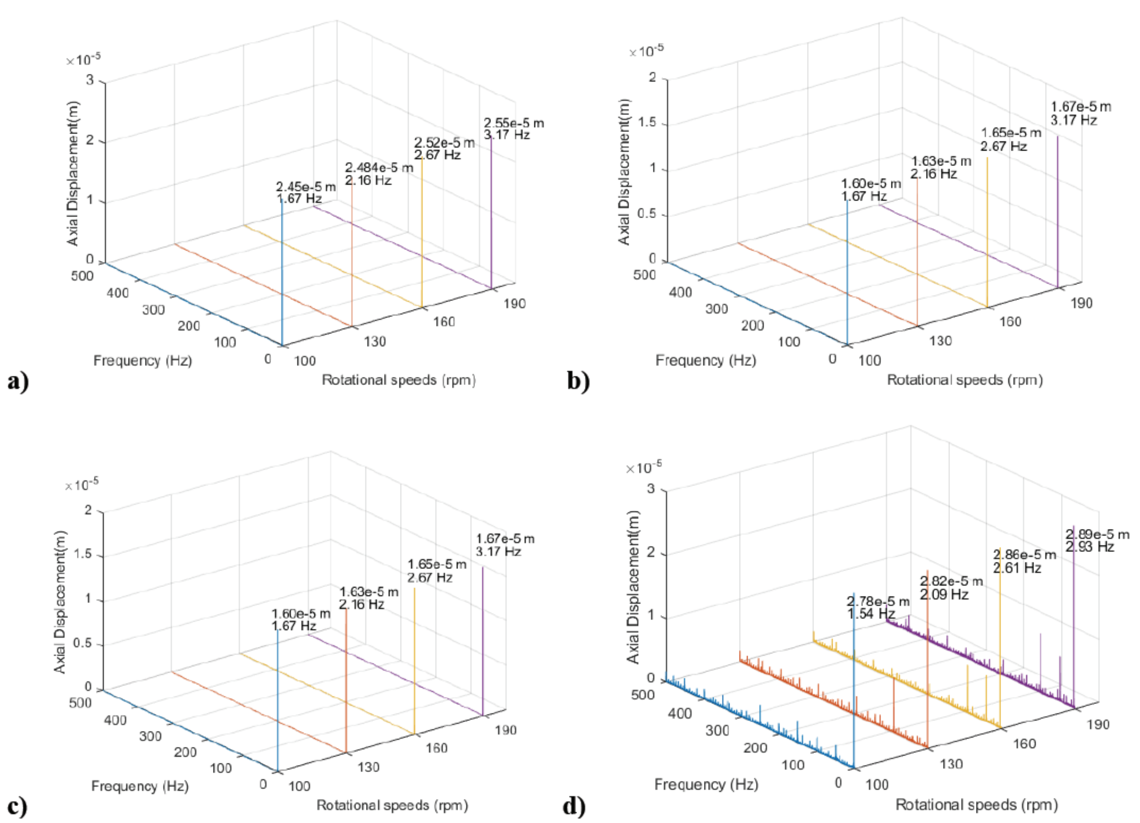

Figure 4. *Axial displacement results at ω=100-190 rpm. a) Model 1, b) Model 2, c) Model 3, d) Experiment*

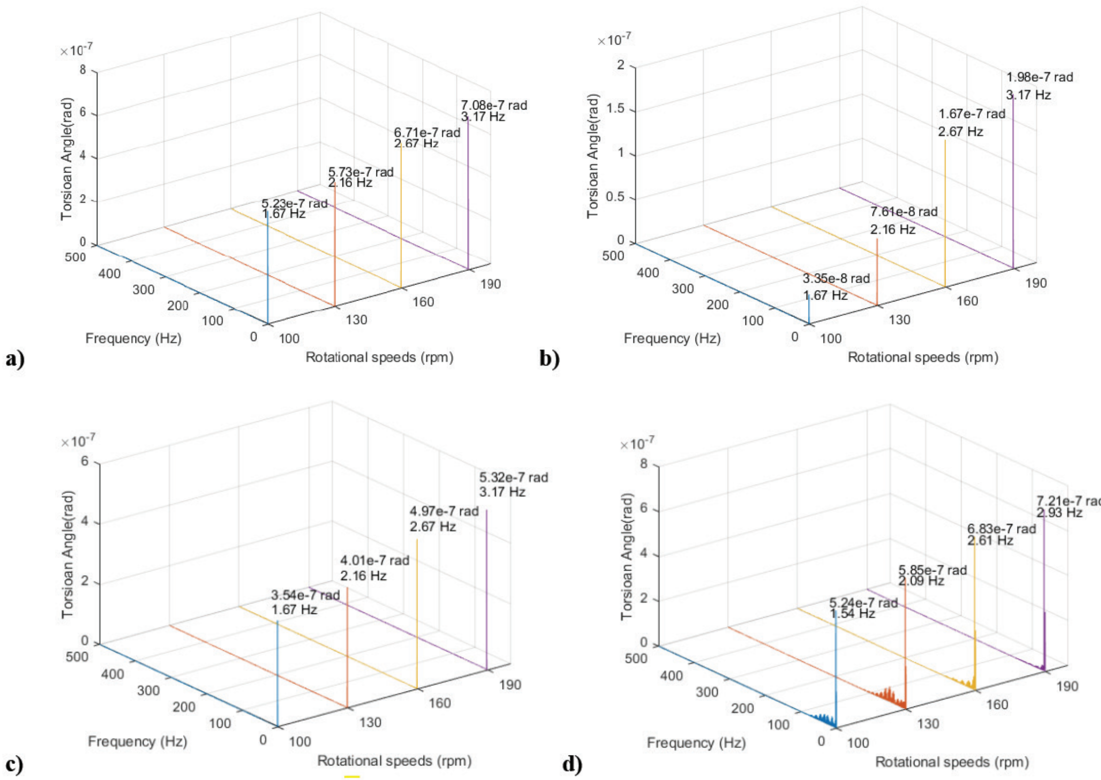

Figure 5. *Torsional angle results at ω=100-190 rpm a) Method 1, b) Method 2, c) Method 3, d) Experiment*

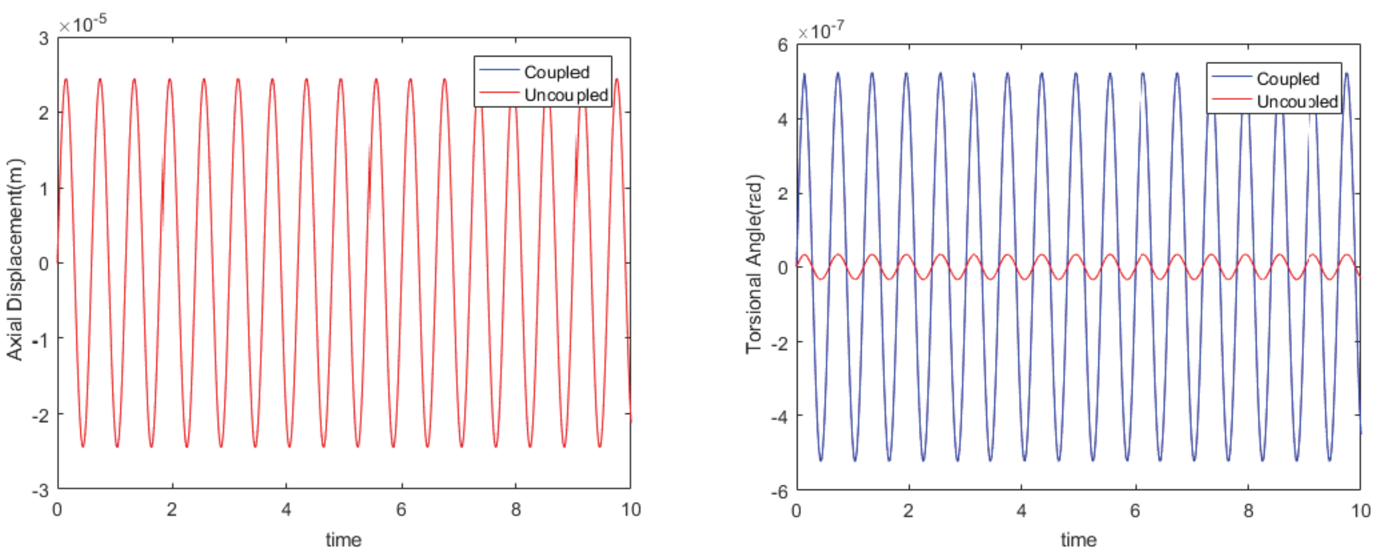

Figure 6. *Axial displacements and torsional angles for Model 1 at 100 rpm*

vibration effect could not be modeled by the hydrodynamic effects in Method 2 due to the lack of a propeller. Because of the inability to calculate hydrodynamic coefficients in Model 2, axial displacement and torsional angle are calculated for uncoupled vibration. Figure 4 indicates the alteration in axial vibration of experiment and numerical models by increasing rotational speed. Numerical and experimental results are given for a range of rotational speeds (100-190 rpm) to find out if they match well with each other; also, the similarity of error margins for different speed values increased the reliability of the experiment. Figure 5 2.78×10^{-5} m for the experiment at 100 rpm rotational speed, respectively. As might be expected, the test result is higher than numerical predictions owing to the imperfection of theoretical models, but the margin of error is low and numerical methods are very much compatible with experiment results. The results obtained from Model 2 and Model 3 show that the coupled vibration for each rotational speed value has virtually no effect on axial displacement. By comparing Model 1 and Model 3, it was deduced that the bearings added to Model 3 reduced axial displacement for each rotational speed value by increasing stiffness and removing Model 3 based on the results.

Figure 5 shows the alternation in the torsional angle of experimental and numerical models by increasing rotational speed. It is observed that the torsional angle of all numerical models is lower than the experimental data. Nevertheless, the slope of curves in the figure are similar, indicating that the numerical models yield identical results despite the margin of error. Additionally, Model 1 performed very close results to the experiment. The maximum torsional angle for Model 2 and Model 3 does not match reveals that the coupled vibration for each rotational speed value impacts torsional vibration. By comparing Model 1 and Model 3, it was found that the bearings added to Model 3 reduced the torsional angle for each rotational speed value and removed Model 3 from the results of the experiment. Further, the bearings in Model 3 diminished the longitudinal vibrations, including the torsional angle, due to the coupling effect, unlike Model 1.

Figure 6 shows the coupled and uncoupled vibration forms are given for Model 1 at 100 rpm shaft speed. Coupled and uncoupled vibration amplitudes for longitudinal vibration, as shown in Figure 6, are 2.45×10^{-5} m. In Figure 7, the coupled and uncoupled vibration amplitudes for torsional vibration are 5.23×10^{-7} rad and 3.35×10^{-8} rad, according to the order. Due to the lack of the propeller in the system, the results of hydrodynamic effects are not calculated. Thus, Model 2 is designed only for uncoupled vibrations, and Model 2 can only be compared with uncoupled vibration models. When examining differences between Model 2 with Model 1, which is an uncoupled vibration model, the bearings in Model 2 only have an impact on axial displacement.

In Figure 7, the displacement values at 100 rpm shaft speed are given for Model 3. When Model 1 compares the effect of coupled and uncoupled vibrations, the coupling effect on the torsional angle is highly efficient, but it has no impact on the axial displacement. Adding bearings to the system with Model 3 did not change this situation, and the coupling effect only affects the torsional angle in the system.

Figure 8 depicts the frequency of the force results from both experiment and numerical models for various rotational speed numbers. Since frequency values for longitudinal vibrations are tantamount to torsional vibrations, they are displayed in one graphic. The frequency of the external force is directly related to the speed of the shaft for numerical models and experiments. In order to detect the forcing frequency of the experiment and the margin of error, the transient response analysis was used. It was found that the margin of error is 8% for 100 rpm and decreases until 160 rpm. However, thereafter it reincreased to 190 rpm. The validity of the experiment has also been controlled in this way.

5. Conclusion and Comments

Three numerical models are used to the dynamic behaviors of coupled torsional-longitudinal vibration for propulsion shaft system subjected to exciting torque and longitudinal force. The dynamic response of displacements and frequency response for the system with individual and

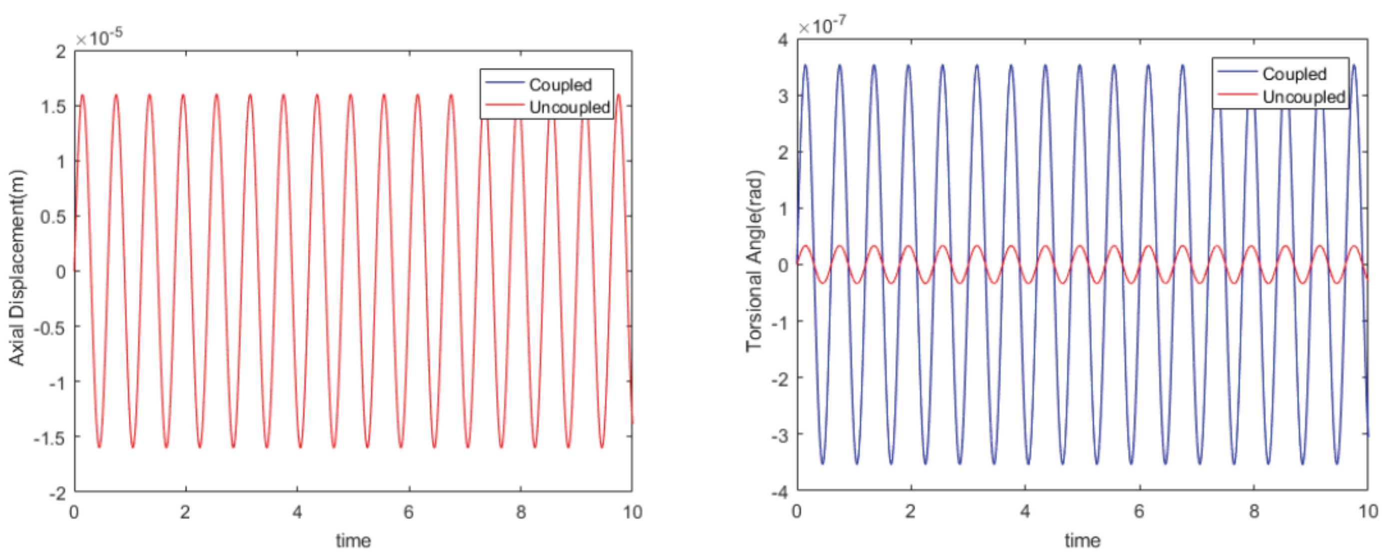

Figure 7. *Axial displacements and torsional angles for Model 3 at 100 rpm*

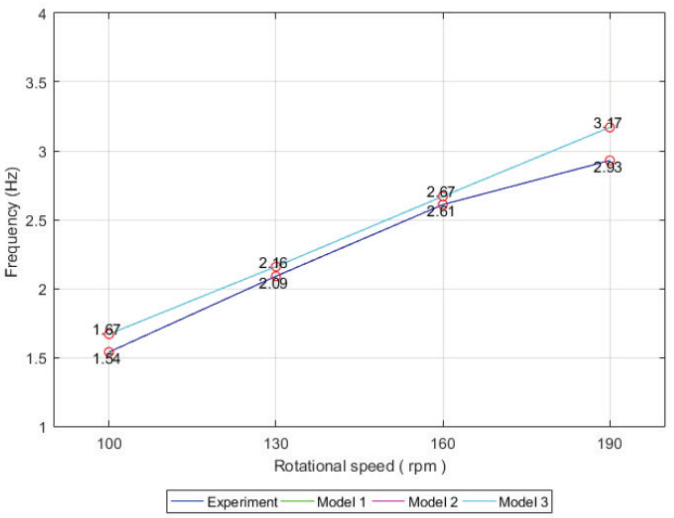

Figure 8. *The driving frequency results at ω=100-190 rpm*

coupled incentives are discussed in detail. Some conclusions are obtained as follows:

The coupling effect is not found during the axial displacement, but it is highly effective on the torsion angle. When the effect of the bearings on the system was considered, the axial displacement and torsion angle values decreased as stiffness increased, and the experimental results were removed. Likewise, it was inferred that the bearings reduced the axial displacement by increasing stiffness for uncoupled vibration and reduced the torsion angle by the coupling effect. This inference leads to obtaining the result that torsional and longitudinal vibration are mutually coupled with each other.

The propulsion shaft system was overly simplified and unrealistic when it was considered without bearings. In contrast, the inclusion of bearings in the numerical model increased the margin of error for the coupled torsion angle and longitudinal displacement. As a result, when the system was brought closer to reality by adding bearings to Model 1, despite providing a fast solution for coupled torsional-longitudinal vibration problems, Model 1 was inconvenient and invalid in a realistic propulsion shaft system with an increased error rate.

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Authorship Contributions

Concept design: A. N. Halilbeşe, O. A. Özsoysal, Data Collection or Processing: A. N. Halilbeşe, O. A. Özsoysal, Analysis or Interpretation: A. N. Halilbeşe, O. A. Özsoysal, Literature Review: A. N. Halilbeşe, O. A. Özsoysal, Writing, Reviewing and Editing: A. N. Halilbeşe, O. A. Özsoysal.

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ORIGINAL RESEARCH (AR)
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Frequency-Domain Ship Motion Code with Python Programming Language

Seyyit Nafiz Arslan[1], Atakan Yavuz[1], Ferdi Çakıcı[2]

[1]Military Factory and Shipyard Management Inc., Ankara, Turkey
[2]Yıldız Technical University, Department of Naval Architecture and Marine Engineering, İstanbul, Turkey

Abstract

In this study, a frequency-domain seakeeping code is established. A container ship was selected as an example to demonstrate the outputs of the code in different headings, ranging from the beam to head waves. Tasai's method is used to obtain two-dimensional hydrodynamic added mass and damping coefficients. For different loading conditions, the damping values for the roll motion can be obtained using Ikeda's method. Froude Krylov and Diffraction terms for pitch and heave motions are computed using the head seas approximation. A user-friendly interface is designed for presenting frequency-domain analyses. Vertical motions, vertical accelerations, and some derived motion characteristics, such as deck wetness, slamming, and absolute vertical accelerations are plotted as transfer functions. The entire procedure is implemented using Python code.

Keywords

Seakeeping code, Tasai's method, Derived motions, Ikeda's method

1. Introduction

In this study, the vertical motions of a ship are calculated in the frequency domain using the Python programming language. The vertical motions of the ship have three degrees of freedom. These motions are called heave, roll, and pitch. Evaluation and optimization of these motions, which are the subject of seakeeping, are extremely crucial for the safety of the passengers and crew. The enhancement of the ship's vertical motions enhances the habitability, operability, mobility, and survivability of the ship.

Ursell's [1] groundbreaking work set the path for the development of ship motion theories. The author demonstrated regular oscillations of a heaving circular cylinder in water and subsequently obtained hydrodynamic characteristics, such as added mass and damping. The velocity potential and conjugate stream function of heave motion in two dimensions were determined using multipole expansion theory [1,2]. Ursell's [1] study was improved by Tasai [3], who used the Lewis conformal mapping method to transform the hydrodynamic coefficients of a circular cylinder into ship-like sections. However, these calculations were insufficient for ships with sharp forms. Frank focused on this problem, and the author developed a pulsating source method to solve it. In this method, the Green function approach was used to represent the velocity potential of the unknown source density [4]. The researchers also published papers revealing the hydrodynamic coefficients of three-dimensional ship geometries. Korvin-Kroukovsky and Jacobs [5] presented the first strip theory approach (the ordinary strip theory) using multipole expansion and mapping techniques. Salvesen et al. [6] developed the "New Strip Theory" method using the Close-Fit method. Another significant development in ship motion was the transition from regular waves to irregular waves in ship motion solutions using a novel method presented by St Denis and Pierson [7]. These two researchers presented a novel statistical energy distribution method that enabled the linearization of irregular waves. This theory (also known as the random process theory) is based on

Address for Correspondence: Ferdi Çakıcı, Yıldız Technical University Faculty of Naval Architecture and Maritime, Department of Naval Architecture and Marine Engineering, İstanbul, Turkey
E-mail: fcakici@yildiz.edu.tr
ORCID ID: orcid.org/0000-0001-9752-1125

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two main assumptions: the sea surface has a normal distribution and the wave amplitude and ship motions are linearly related.

Owing to its speed and reliability, "The Strip Theory" is used in many studies in the seakeeping field, such as comfort onboard analysis and optimization works. The purpose of this study is to develop an in-house seakeeping code. Herein, hydrodynamic coefficients of sectional ship contours are calculated using conformal mapping developed by Lewis [2], and the multipole expansion theory developed by Ursell and Tasai. The novel strip theory by Salvesen et al. [6] was used to calculate the global hydrodynamic coefficients. Roll motion dynamics in the code were included using Ikeda's [8] method.

2. Definition of Ship Model and Coordinate System

Before the theories and methods for this study are explained, the description of the adopted container ship is provided. The body lines and the coordinate system of the ship are given in Figures 1a and 1b, respectively.

This sample container ship taken from the MAXSURF naval architecture program shows the seakeeping code outputs [9]. The main dimensions and several properties of the ship are listed in Table 1. The main reason for selecting this ship is that it features sections (fine sections) that are suitable for Lewis conformal mapping.

To compare the irregular wave results, the proposed limitations are determined in Table 2 [10].

3. Lewis Conformal Mapping

As previously stated, the sectional contours of the ship are obtained using Lewis conformal mapping [2]. Lewis conformal mapping is often simple to use. However, this method does not always result in a successful transformation of the ship's cross-section. The proper Lewis forms must be determined before performing the Lewis conformal mapping. The general transformation formula is given below (Equation 1).

Table 1. *The main dimension and loading conditions of the container ship*

Main Dimensions	Magnitudes	Units
L_{WL} (Length of waterline)	111,187	Meter
B (Breadth)	19.5	Meter
T (Draft)	7,239	Meter
CB (Block coefficient)	0.693	-
ρ (Density of sea)	1.025	t/m^3
Δ (Displaced mass of ship)	11156	Ton
LCB (longitudinal center of buoyancy)	54,030	Meter
LCG (longitudinal center of gravity)	54,030	Meter
VCB (vertical center of buoyancy)	3,783	Meter
VCG (vertical center of gravity)	6	Meter
The gyration radius of pitch motion	29,053	Meter
The gyration radius of roll motion	7.8	Meter

Table 2. *The performance limitations for the given ship*

Motion	Limit	Location
Deck wetness index	30/hour	Bow
Slamming index	20/hour	Keel
Propeller emergence index	90/hour	1/4 propeller diameter
Vertical acceleration	0.2 g (RMS)	Task location
RMS: Root mean square		

$$Z = M_s \sum_{n=0}^{N} (a_{2n-1} \varsigma^{-(2n-1)}) \tag{1}$$

where M_s is the Scale factor, a_{2n-1} represents the conformal mapping coefficients, and N is the number of parameters

The plane of the ship's cross-section (Equation 2) and the plane of the unit circle (Equation 3) are given below. The transverse and vertical coordinates of the ship's cross-section are represented by X and Y, respectively.

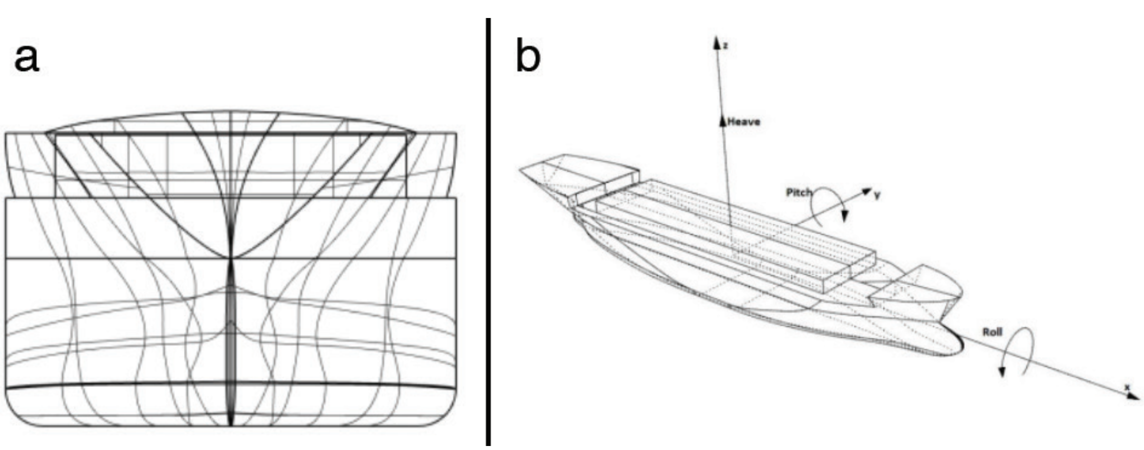

Figure 1. *The body lines (a) and the coordinate system of the container ship (b)*

$$Z = X + iY \quad (2)$$

$$\varsigma = ie^{\alpha}e^{-i\theta} \quad (3)$$

The next step is to perform the Lewis conformal mapping with N=2. The Lewis transformation formula is given below (Equation 4).

$$Z = M_s(a_{-1}\varsigma + a_1\varsigma^{-1} + a_3\varsigma^{-3}) \quad (4)$$

The contour coordinates of this Lewis form can be obtained using $\alpha = 0$, and the transverse and vertical coordinates of the ship's cross-section contour are given below (Equations 5 and 6) (a_{-1}=+1).

$$X_0 = M_s((1+a_1)\sin\theta - a_3\sin 3\theta) \quad (5)$$

$$Y_0 = M_s((1-a_1)\cos\theta + a_3\cos 3\theta) \quad (6)$$

The scale factor is given below (Equation 7). B_s is the sectional breadth along the ship.

$$M_s = \frac{B_s/2}{1+a_1+a_3} \quad (7)$$

In Equations 8 and 9, the half breadth to draft ratio and the sectional area coefficient are given, respectively.

$$H_0 = \frac{B_s/2}{T_s} = \frac{1+a_1+a_3}{1-a_1+a_3} \quad (8)$$

$$\sigma_s = \frac{A_s}{B_sT_s} = \frac{\pi}{4}\cdot\frac{1-a_1^2-3a_3^2}{(1+a_3)^2-a_1^2}, \quad (9)$$

where A_s and T_s represent the cross-sectional areas and drafts along the ship, respectively. With these equations (Equations 8 and 9), Equation 10 can be obtained.

$$c_1a_3^2 + c_2a_3 + c_3 = 0 \quad (10)$$

The solutions of Equation 10 (Equations 11-13) are given below.

$$c_1 = 3 + \frac{4\sigma_s}{\pi} + \left(1-\frac{4\sigma_s}{\pi}\right)\cdot\left(\frac{H_0-1}{H_0+1}\right)^2 \quad (11)$$

$$c_2 = 2c_1 - 6 \quad (12)$$

$$c_3 = c_1 - 4 \quad (13)$$

With these solutions, the Lewis conformal mapping coefficients can be determined (Equations 14 and 15) [11].

$$a_3 = \frac{-c_1+3+\sqrt{9-2c_1}}{c_1} \quad (14)$$

$$a_1 = \frac{H_0-1}{H_0+1}\cdot(a_3+1) \quad (15)$$

4. Tasai's Theory

Calculating the three-dimensional hydrodynamic coefficients of the ship is often complicated. Therefore, using the strip theory method, these three-dimensional coefficients can be acquired based on two-dimensional hydrodynamic coefficients of the ship. Accordingly, the sectional added mass and damping coefficients for heave motion were determined by Tasai [3] in 1959. In this section, two-dimensional hydrodynamic added mass and damping coefficients for heave motion are obtained using Tasai's method. The approximations for this method are that the forward speed of the ship is zero, the ship is in deep water, and an infinitely long cylinder is in the free surface of a fluid.

To calculate the sectional added mass and damping coefficients for heave motion, A_0, B_0, M_0, and N_0 coefficients must be determined, and the values required to compute these coefficients are given below (Equations 16-20).

$$\phi_{B_c} = \pi e^{-\nu Y}\cos(\nu X) \quad (16)$$

$$\phi_{B_s} = \pi e^{-\nu Y}\sin(\nu X) + \int_0^\infty \frac{\nu\sin(kY) - k\cos(kY)}{k^2+\nu^2}e^{-k|X|}dk \quad (17)$$

$$\psi_{B_c} = \pi e^{-\nu Y}\sin(\nu X) \quad (18)$$

$$\psi_{B_s} = -\pi e^{-\nu Y}\cos(\nu X) + \int_0^\infty \frac{\nu\cos(kY) + k\sin(kY)}{k^2+\nu^2}e^{-k|X|}dk \quad (19)$$

$$\psi_{A0_{2m}}(\theta) = \sin(2m\theta) - \frac{\xi_b}{\lambda_a}\sum_{n=0}^{N}\left\{(-1)^n\frac{2n-1}{2m+2n-1}a_{2n-1}\sin((2m+2n-1)\theta)\right\}, \quad (20)$$

where: $\frac{\xi_b}{\lambda_a} = \frac{\omega_e^2}{g}M_s$ or $\xi_b = \frac{\omega_e^2 B_s}{2g}$ and $\lambda_a = \sum_{n=0}^{N} a_{2n-1}$ and $\nu = \frac{\omega_e^2}{g}$,

where ω_e is the encounter frequency and g is the gravitational acceleration [11]. The integrations in Equation 17 and Equation 19 can be solved using Porter's [12] method. The convergence is relatively rapid using this method [11]. For P_{2m} and Q_{2m}, two sets of M equations are given below (in this study, M is taken to be 6) (Equations 21, 22).

$$\sum_{m=1}^{M}\left\{P_{2m}\int_0^{\pi/2} f_{2m}(\theta)f_{2n}(\theta)d\theta\right\} = \int_0^{\pi/2}\left(\psi_{B0_c}(\theta) - h(\theta)\psi_{B0_c}(\frac{\pi}{2})\right)f_{2n}(\theta)d\theta \; ; n = 1,......,M \quad (21)$$

$$\sum_{m=1}^{M}\left\{Q_{2m}\int_0^{\pi/2} f_{2m}(\theta)f_{2n}(\theta)d\theta\right\} = \int_0^{\pi/2}\left(\psi_{B0_s}(\theta) - h(\theta)\psi_{B0_s}(\frac{\pi}{2})\right)f_{2n}(\theta)d\theta \; ; n = 1,......,M \quad (22)$$

In which:

$$f_{2m}(\theta) = -\psi_{A0_{2m}}(\theta) + h(\theta)\psi_{A0_{2m}}(\frac{\pi}{2}) \text{ and } h(\theta) = \frac{2X_0}{B_s} = -\frac{1}{\lambda_a}\sum_{n=0}^{N}\left\{(-1)^n a_{2n-1}\sin((2n-1)\theta)\right\}$$

Now, A_0, B_0, M_0, and N_0 coefficients can be expressed as follows (Equations 23-26):

$$A_0 = \psi_{B0_c}(\frac{\pi}{2}) + \sum_{m=1}^{\infty}\left\{P_{2m}\psi_{A0_{2m}}(\frac{\pi}{2})\right\} \quad (23)$$

$$B_0 = \psi_{B0_s}(\frac{\pi}{2}) + \sum_{m=1}^{\infty}\left\{Q_{2m}\psi_{A0_{2m}}(\frac{\pi}{2})\right\} \quad (24)$$

$$M_0 = -\frac{1}{\lambda_a}\int_0^{\pi/2}\phi_{B0_s}(\theta)\sum_{n=0}^{N}\{(-1)^n(2n-1)a_{2n-1}\cos((2n-1)\theta)\}d\theta$$
$$-\frac{1}{\lambda_a}\sum_{m=1}^{M}\{(-1)^m Q_{2m}\sum_{n=0}^{N}\{\frac{(2n-1)^2}{(2m)^2-(2n-1)^2}a_{2n-1}\}\} \quad (25)$$
$$+\frac{\pi\xi_b}{4\lambda_a^2}(Q_{21}+\sum_{m=1}^{N}\{(-1)^m Q_{2m}\sum_{n=0}^{N-m}\{(2n-1)a_{2n-1}a_{2m+2n-1}\}\}), \quad for: M \geq N$$

$$N_0 = -\frac{1}{\lambda_a}\int_0^{\pi/2}\phi_{B0_c}(\theta)\sum_{n=0}^{N}\{(-1)^n(2n-1)a_{2n-1}\cos((2n-1)\theta)\}d\theta$$
$$-\frac{1}{\lambda_a}\sum_{m=1}^{M}\{(-1)^m P_{2m}\sum_{n=0}^{N}\{\frac{(2n-1)^2}{(2m)^2-(2n-1)^2}a_{2n-1}\}\} \quad (26)$$
$$+\frac{\pi\xi_b}{4\lambda_a^2}(P_{21}+\sum_{m=1}^{N}\{(-1)^m P_{2m}\sum_{n=0}^{N-m}\{(2n-1)a_{2n-1}a_{2m+2n-1}\}\}), \quad for: M \geq N$$

Finally, as shown below, the sectional potential added mass and damping coefficients can be determined (Equations 27, 28).

$$a_z = \frac{\rho B_s^2}{2}\cdot\frac{M_0B_0+N_0A_0}{A_0^2+B_0^2} \quad (27)$$

$$b_z = \frac{\rho B_s^2}{2}\cdot\frac{M_0A_0-N_0B_0}{A_0^2+B_0^2}\omega_e \quad (28)$$

5. Salvesen et al. [6] Strip Theory

Strip theory is a useful theory that enables us to calculate the global hydrodynamic coefficients of a three-dimensional ship using two-dimensional hydrodynamic coefficients of the ship sections. Two-dimensional coefficients calculation is preferable since it is much easier than directly determining coefficients of a three-dimensional ship. There are certain restrictions when using the strip theory. These restrictions can be summarized as follows: the flow must be potential, and the body of the ship must be slender. As previously stated, the focus of this study is on frequency-domain ship vertical motions. Therefore, the vertical motions of the ship are heave, roll, and pitch motions, which are all within the scope of seakeeping. It is assumed that heave and pitch motions are coupled motions, while roll motion is an uncoupled motion. Heave, pitch, and roll motions equations are listed below, respectively (Equations 29, 30, and 31).

$$(M+A_{33})\ddot{\eta}_3+B_{33}\dot{\eta}_3+C_{33}\eta_3+A_{35}\ddot{\eta}_5+B_{35}\dot{\eta}_5+C_{35}\eta_5=F_3e^{i\omega_e t} \quad (29)$$

$$(I_5+A_{55})\ddot{\eta}_5+B_{55}\dot{\eta}_5+C_{55}\eta_5+A_{53}\ddot{\eta}_3+B_{53}\dot{\eta}_3+C_{53}\eta_3=F_5e^{i\omega_e t} \quad (30)$$

$$(I_4+A_{44})\ddot{\eta}_4+B_{44}\dot{\eta}_4+C_{44}\eta_4=F_4e^{i\omega_e t} \quad (31)$$

In which:

j, k: Subscripts (j, k=3, 4, 5 refer to heave, roll, and pitch, respectively)

A_{jk}: Added mass coefficients

B_{jk}: Damping coefficients

C_{jk}: Hydrostatic restoring coefficients

F_j: Exciting forces ad moments

I_j: Moment of inertia

M: Mass of the ship

η_j: Displacements

$\dot{\eta}_j$: Velocities

$\ddot{\eta}_j$: Accelerations

The global hydrodynamic coefficients of the heave, roll, and pitch motion equations are provided below (Equations 32-46) [6].

$$A_{33}=\int_{-L/2}^{L/2}a_z dx-\frac{V}{\omega_e^2}b_z^A \quad (32)$$

$$B_{33}=\int_{-L/2}^{L/2}b_z dx+Va_z^A \quad (33)$$

$$A_{35}=-\int_{-L/2}^{L/2}xa_z dx-\frac{V}{\omega_e^2}B_{33}^0+\frac{V}{\omega_e^2}x_Ab_z^A-\frac{V^2}{\omega_e^2}a_z^A \quad (34)$$

$$B_{35}=-\int_{-L/2}^{L/2}xb_z dx+VA_{33}^0-Vx_Aa_z^A-\frac{V^2}{\omega_e^2}b_z^A \quad (35)$$

$$A_{53}=-\int_{-L/2}^{L/2}xa_z dx+\frac{V}{\omega_e^2}B_{33}^0+\frac{V}{\omega_e^2}x_Ab_z^A \quad (36)$$

$$B_{53}=-\int_{-L/2}^{L/2}xb_z dx-VA_{33}^0-Vx_Aa_z^A \quad (37)$$

$$A_{55}=\int_{-L/2}^{L/2}x^2a_z dx+\frac{V^2}{\omega_e^2}A_{33}^0-\frac{V}{\omega_e^2}x_A^2b_z^A+\frac{V^2}{\omega_e^2}x_Aa_z^A \quad (38)$$

$$B_{55}=\int_{-L/2}^{L/2}x^2b_z dx+\frac{V^2}{\omega_e^2}B_{33}^0+Vx_A^2a_z^A+\frac{V^2}{\omega_e^2}x_Ab_z^A \quad (39)$$

$$C_{33}=\rho g\int_{-L/2}^{L/2}B_s dx=\rho gA_{WP} \quad (40)$$

$$C_{35}=C_{53}=-\rho g\int_{-L/2}^{L/2}xB_s dx \quad (41)$$

$$C_{55}=\rho g\int_{-L/2}^{L/2}x^2B_s dx \quad (42)$$

$$I_5=M\cdot k_{yy}^2\ ;\ 0.25L_{WL}\leq k_{yy}\leq 0.30L_{WL} \quad (43)$$

$$I_4=M\cdot k_{xx}^2\ ;\ 0.35B\leq k_{xx}\leq 0.40B \quad (44)$$

$$0.20\cdot I_4<A_{44}<0.30\cdot I_4 \quad (45)$$

$$C_{44}=\rho\cdot g\cdot\nabla\cdot GM_t \quad (46)$$

In which:

V denotes ship forward speed, b_z^A denotes b_z for aftermost section, a_z^A denotes a_z for aftermost section, B_{33}^0 denotes speed-independent part of B_{33}, x_A denotes x-coordinate of aftermost cross-section, A_{33}^0 denotes speed-independent part of A_{33}, k_{yy} denotes pitch gyration radius, k_{xx} denotes roll gyration radius, GM_t denotes metacentric height, and ∇ denotes displaced volume of the ship.

As can be seen, there is no equation for B_{44} (roll damping coefficient) because the roll damping coefficient is obtained using Ikeda's [8] method. The right-hand side of the heave and pitch motion equations are solved using the head seas approximation. Heave, pitch, and roll exciting forces and moments are given, (Equations 47-49) [6]. It is worth noting that the head seas for heave force and pitch moment assumption used in the code may produce realistic results only for the 160° to 180° range [9].

$$F_3 = \zeta_a \int e^{ikx} e^{-kT_s\sigma_s} \left\{ \rho g B_s - \omega_0 (\omega_e a_z - ib_z) \right\} dx - \zeta_a \frac{V}{i\omega_e} e^{ikx_A} e^{-kT_s\sigma_s} \omega_0 (\omega_e a_z{}^A - ib_z{}^A) \tag{47}$$

$$F_5 = -\zeta_a \int e^{ikx} e^{-kT_s\sigma_s} \left\{ x\left[\rho g B_s - \omega_0 (\omega_e a_z - ib_z)\right] - \frac{V}{i\omega_e} \omega_0 (\omega_e a_z - ib_z) \right\} dx + \zeta_a \frac{V}{i\omega_e} e^{ikx_A} e^{-kT_s\sigma_s} \omega_0 x_A (\omega_e a_z{}^A - ib_z{}^A) \tag{48}$$

$$F_4 = C_{44} \cdot \zeta_a \cdot k \cdot \sin\mu \tag{49}$$

In which, k is the wavenumber, ω_0 is the wave frequency, μ is the angle of encounter, T_s is the sectional draught, σ_s is the sectional area coefficient, and ζ_a is a small wave amplitude. After computing all global coefficients, exciting forces, and moments, Equations 29, 30, and 31 can be solved in the frequency domain using any linear equation solver method. Heave, roll, and pitch displacements are the results of the linear equation. It is worth noting that, unlike the heave displacement, roll and pitch are angularly displaced. Heave, roll, and pitch transfer functions (TF) are given below (Equations 50-52).

$$Heave\ TF = \frac{\eta_3}{\zeta_a} \tag{50}$$

$$Roll\ TF = \frac{\eta_4}{\zeta_a k} \tag{51}$$

$$Pitch\ TF = \frac{\eta_5}{\zeta_a k} \tag{52}$$

6. The Outputs of the Present Seakeeping Code

The outputs of the seakeeping code are listed in this section. Before demonstrating the important results, some inputs used in the seakeeping code are explained in Table 3 (these inputs are the locations for propeller emergence, slamming, deck wetness, and absolute vertical acceleration are locations 1, 2, 3, and 4, respectively).

The longitudinal (x_p) and the transverse (y_p) distances are measured with the center of gravity. Here PSD, T_{L2}, and F_{L3} represent propeller shaft depth, draft at location 2, and freeboard at location 3, respectively. It is worth noting that the upper side of the free surface and the head side of the ship are considered positive directions. In this study, sea states 5 and 6 (significant wave heights of the sea state 5 and 6 are 3.25 and 5 meters) were selected to show the irregular sea outputs.

Table 3. *Some seakeeping code inputs*

	Inputs	Units
Angle of encounter	90°:180°:15°	Degree
Fn (Froude number)	0.2	Dimensionless
Sea state (SS)	5 and 6	-
Sea	Black Sea	-
Wave spectrum	Bretschneider wave spectrum	-
Location 1	x_p: -51.678, y_p: 0, PSD: -4.385	Meter
Location 2	x_p: 45.444, y_p: 0, T_{L2}: -7.239	Meter
Location 3	x_p: 45.444, y_p: 7.24, F_{L3}: 5.66	Meter
Location 4	x_p: -45.527, y_p: 9.171	Meter

The general steps and detailed inputs of the seakeeping code are given as flowcharts in Figures 2a and 2b, respectively.

In Figure 3a, and Figure 3b the sectional added mass coefficients for the 16th and 25th cross-sections of the container ship are compared with the MAXSURF outputs.

In Figure 4a and Figure 4b, the sectional damping coefficients for the 16th and 25th cross-sections of the container ship are compared with the MAXSURF outputs.

The results of the present seakeeping code (sectional added mass and damping coefficients) correlate well with the MAXSURF results, As shown in Figures 3 and 4. Figure 5a and Figure 5b compare MAXSURF commercial software outputs with certain global hydrodynamic added mass and damping coefficients, A_{35} and B_{53}.

The results of the seakeeping code, in terms of global added mass and damping, are also highly reliable. These results can be seen in Figures 5a and 5b.

The solution of Equation 29-31 for F_n=0.2 provided the regular sea results. Heave, roll, and pitch TFs are demonstrated in Figures 6a, 6b, and 6c, respectively. It is worth noting that the input heading angles used ranged from 90° to 180° as seen from the figures below. However, the assumption of head seas is only valid for the 160° to 180° range. Therefore, the accuracy of the outputs outside of this range should be debated.

Following the demonstration of the general regular sea results, certain irregular wave outputs were also provided. These results are compared with the proposed limits in Table 2.

Figures 7a, 7b, and 7c demonstrate the number of propeller emergence, slamming, and deck wetness, respectively, for

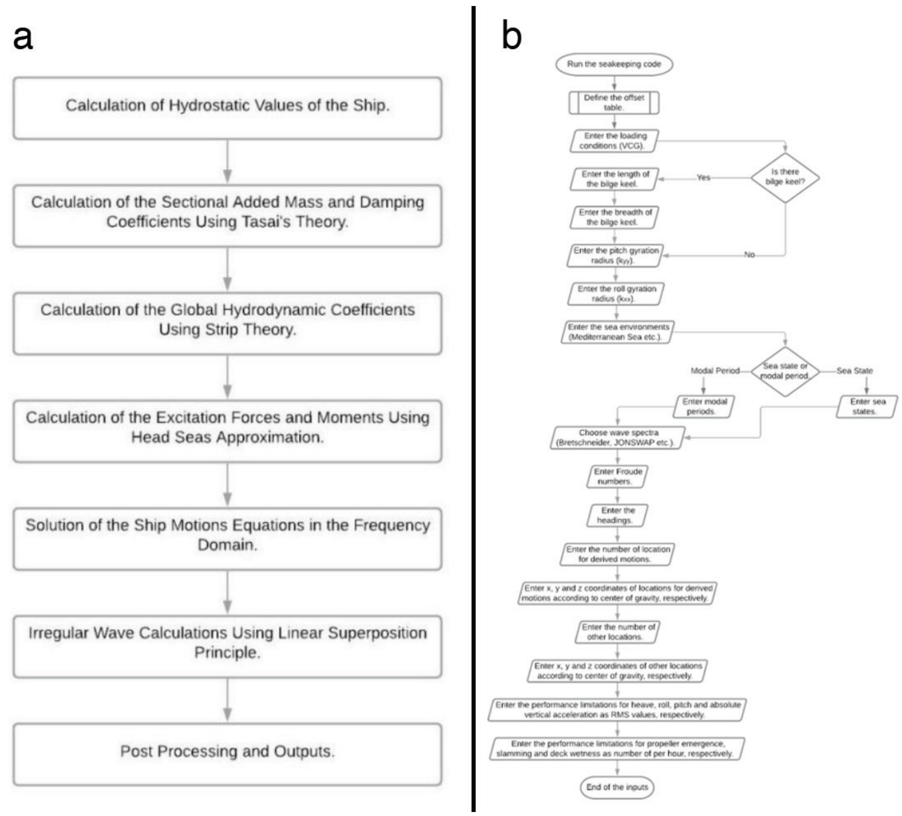

Figure 2. *General steps (a) and detailed inputs of the seakeeping code (b)*

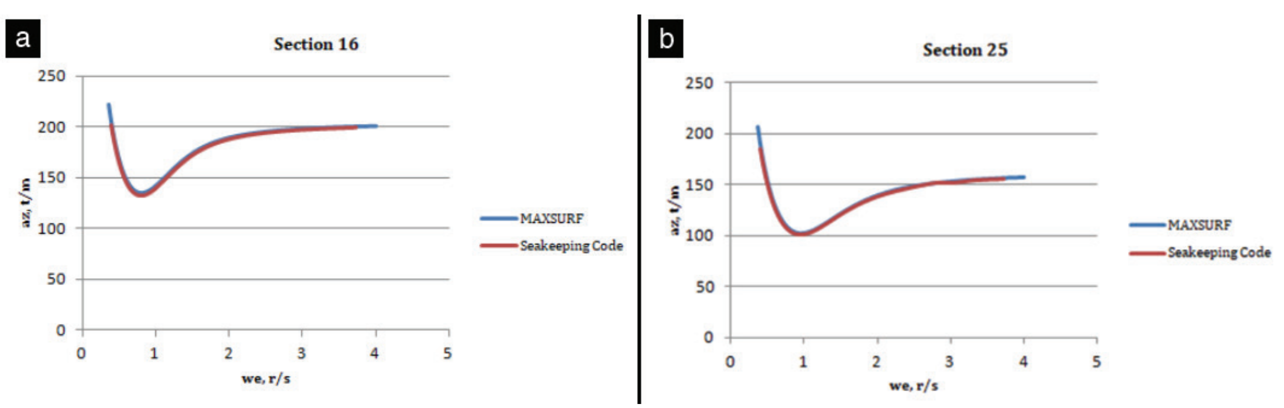

Figure 3. *Sectional added mass coefficients comparison for sections 16 and 25*

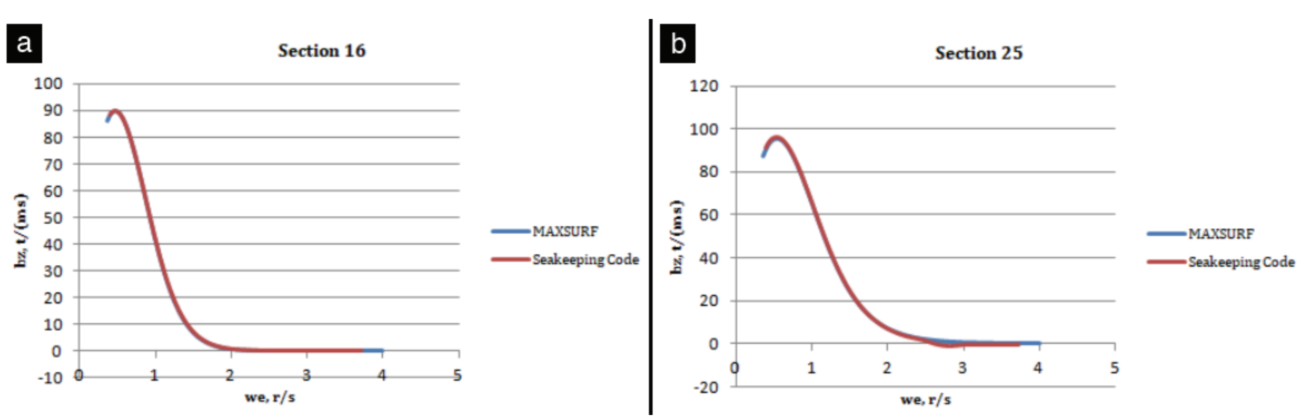

Figure 4. *Sectional damping coefficients comparison for Sections 16 and 25*

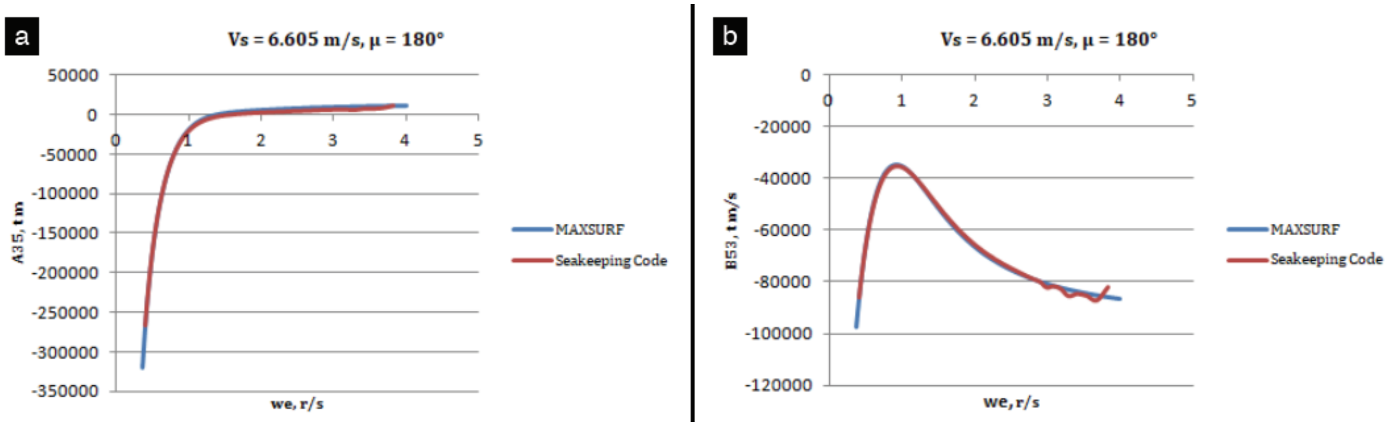

Figure 5. *Comparison of* A_{35} *and* B_{53}

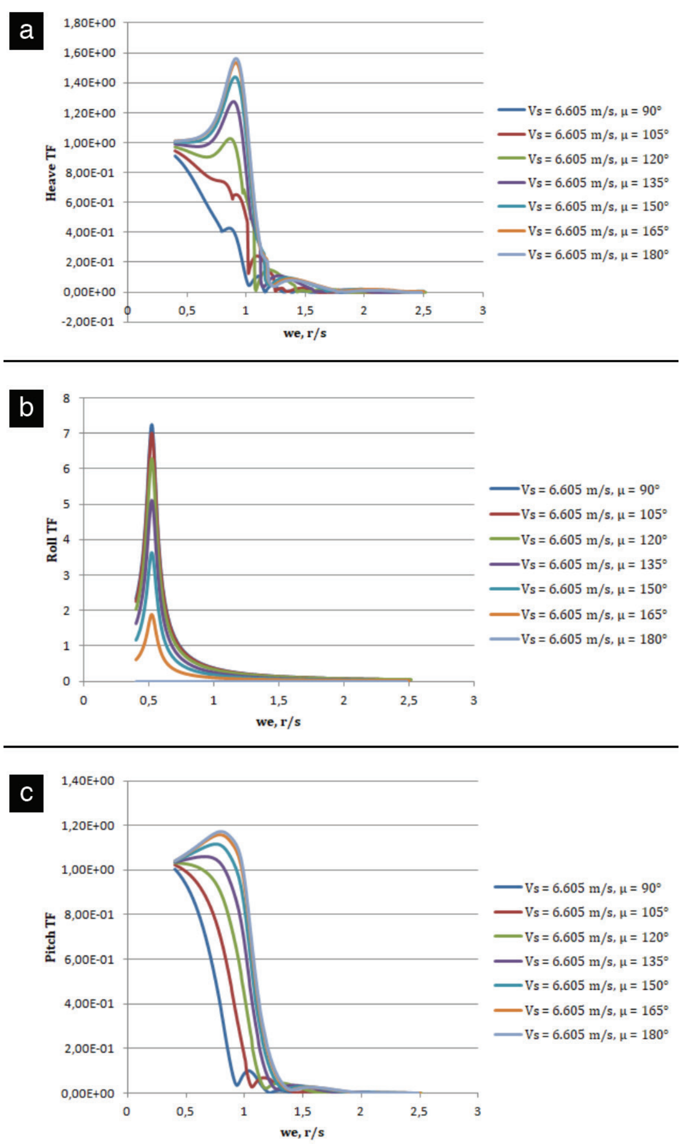

Figure 6. *Heave, roll, and pitch TF,* F_n*=0.2*

sea state 6. As previously stated, locations 1, 2, and 3 are for propeller emergence, slamming, and deck wetness, respectively. The absolute vertical acceleration values are given for the sea states 5 and 6 are shown in Figures 7d and 7e, respectively. These vertical acceleration calculations are made for location 4.

7. Conclusion

In this study, the frequency-domain ship motions are coded using Python programming language. The container ship is selected as an example to demonstrate the output of the present seakeeping code. This particular ship was selected because all its sections correlate with those determined by Lewis forms. All ship characteristics are determined by the trapezoid numerical integration method in the code with the use of the ship's offset data. Using Ursell and Tasai's multipole expansion theory and conformal mapping, the sectional added mass and damping coefficients are determined. Lewis conformal mapping (N=2) is performed to obtain the hydrodynamic coefficients. After obtaining the sectional hydrodynamic coefficients, the global hydrodynamic coefficients and the amplitudes of the exciting forces and moments are determined using the strip theory and head seas approximation. For roll motion damping values, Ikeda's method is utilized. After determining global coefficients, heave, pitch, and roll motion equations are solved, and the TFs of these displacements (heave, pitch, and roll) are properly obtained. The irregular wave calculations can be performed using the obtained TFs and the linear superposition principle. Several spectra and sea environments are defined in the code and based on these definitions, the vertical acceleration root mean square, number of propeller emergence per hour, number of slamming per hour, and number of deck wetness per hour are computed appropriately. The entire process is performed using Python code.

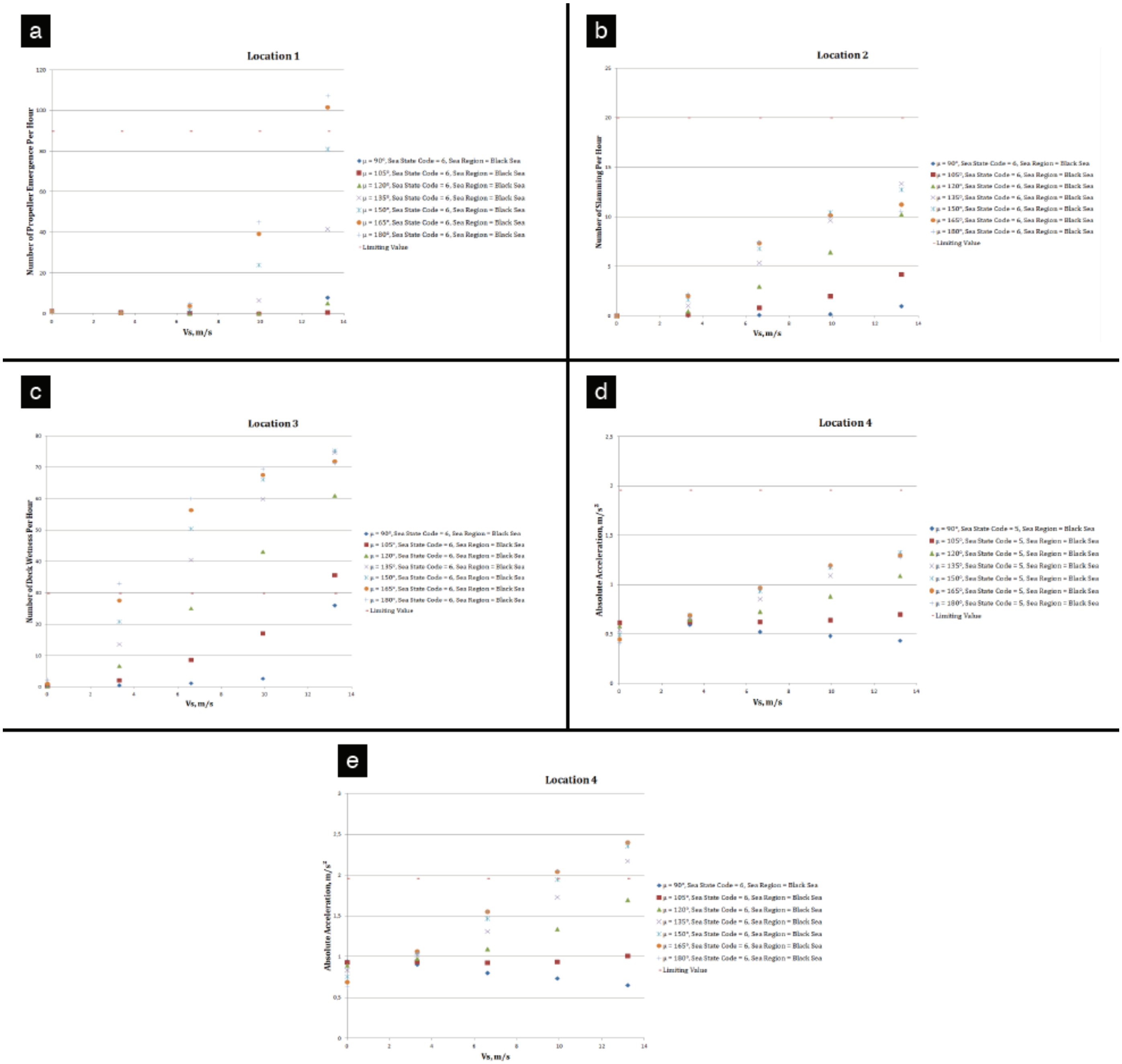

Figure 7. *Certain irregular sea results*

This study applied Lewis conformal mapping and head seas approximation for the conformal mapping method and sectional excitation terms, respectively. Close-fit conformal mapping and arbitrary wave heading will be considered in future studies.

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Post GMC'21 Conference

Osman Turan

University of Strathclyde, Department of Naval Architecture, Ocean & Marine Engineering, Maritime Human Factors Centre (MHFC), Glasgow, United Kingdom

The 4th Global Maritime Conference (GMC'21), which was addressed by International Maritime Organization (IMO) General Secretary, Mr. Kitack Lim, took place as an online event on November 18 to 19, 2021. GMC'21 was organized with the partnership of the Turkish Chamber of Marine Engineers (TMMOB), the University of Strathclyde, (UK), Constanta Maritime University (Romania), and Iskenderun Technical University (Turkey). The event was extremely successful, with academics from over 19 countries presenting more than 110 high-quality scientific papers on various international maritime challenges, including the most pressing issues, "Decarbonization in the Maritime Sector" and "Effects of the Pandemic on Maritime Education and Maritime Transport."

To limit the rise in global temperature to 1.5 °C, in accordance with the Paris climate challenge agreement, IMO (2018) agreed to a greenhouse gas (GHG) strategy for shipping that requires the shipping sector to reduce its emissions by at least 50% by 2050, compared to 2008, including a reduction in the carbon intensity from international shipping by at least 40% by 2030. These GHG emission targets for shipping require disrupting technological innovations and smarter operational practices, including energy-efficient ship design and technologies, non-fossil fuels such as hydrogen and ammonia produced using green electricity at a commercial scale, voyage optimization, and weather routing and port operations.

COP'26, which took place from October 31 to November 13, 2021, in Glasgow, hosted a number of shipping-related events, which highlighted the need for urgent actions to realize zero-emission shipping, including the much-needed policies, infrastructure, and finance for green technologies. Shipping, while trying to address the environmental challenges, has been the most adversely affected industry by the COVID-19 pandemic, as several ships ceased trading, the cruise industry stopped operating completely, and thousands of seafarers were trapped onboard ships for months. Furthermore, because of the travel and meeting restrictions, cadet education and seafarer training have suffered in a major way, resulting in certification and employment issues.

GMC'21 was a timely and vibrant international conference, demonstrating the capabilities and importance of academic research power in developing solutions to face immediate challenges and achieving ambitious environmental targets. It was encouraging to listen to so many young researchers from various parts of the world, presenting their high-quality research on a number of topics covered by the conference, including Alternative Fuels and Renewable Energy, Naval Architecture and Offshore Technologies, Autonomous Ships and Systems; Maritime Policy, Law and Governance; Port Operations and Technologies; Maritime Safety and Security, Navigation and Marine Traffic, Maritime Transportation and Economics; Maritime Education, Maritime Crew Management, and Seafarers Health and Environment.

The challenges the Maritime industry is facing are global and are significantly impacting the industry. These challenges can only be addressed by promoting and harnessing the industry-academia, and national and international academic collaborations. It was encouraging to see that many papers presented at GMC'21 were the outputs of international academic collaborations. Industry engagement in universities and maritime focus research is of paramount importance. It was also pleasing to see that some papers had coauthors from industry. However, GMC'23 must build on the success of GMC'21 and should target much

Address for Correspondence: Osman Turan, University of Strathclyde, Department of Naval Architecture, Ocean & Marine Engineering, Maritime Human Factors Centre (MHFC), Glasgow, United Kingdom
E-mail: o.turan@strath.ac.uk
ORCID ID: orcid.org/0000-0003-1877-8462

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wider industry involvement. In the digital age, real-world data is extremely valuable to gain insights and develop the much-needed solutions. It is crucial that industry supports academia with this data and measurement opportunities, and be a partner in the solution development. The IMO EEXI and CII regulations, which are coming into force in 2023, require another such industry-academia partnership.

Prof. OSMAN TURAN, BSc, MSc, PhD

Professor of Marine Design and the Director of Maritime Human Factors Centre at the Department of Naval Architecture, Marine and Ocean Engineering, University of Strathclyde. His expertise is in Safe and Energy-Efficient Marine design and operations, including maritime human factors. He was the founding partner and the technical director of Safety at Sea ltd between 1999 and 2007. He has published more than 80 journals and 200 conference papers and organized seven international conferences. He has successfully supervised more than 30 PhD students to date.

Prof. Turan has extensive experience in managing projects and acting as international expert reviewers to several large international projects while serving as the international scientific advisor to the Norwegian National project “Smart Maritime Project.” He has been involved in more than 80 research and consultancy projects. Prof. Turan has participated as an investigator in EPSRC’s largest-ever funded marine research projects in energy efficiency: Low Carbon Shipping (2010-2013) and Shipping in Changing Climates (2013-2017). Prof. Turan was the coordinator of the FP7 SEAHORSE project, which received the LR-RINA maritime safety award 2017. Prof. Turan was also the winner of the 2018 TRAVISION (TRA 2018) senior European Researcher award in waterborne transport, organized by the European Commission.

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