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Since 2020, JEMS has been published in English only.

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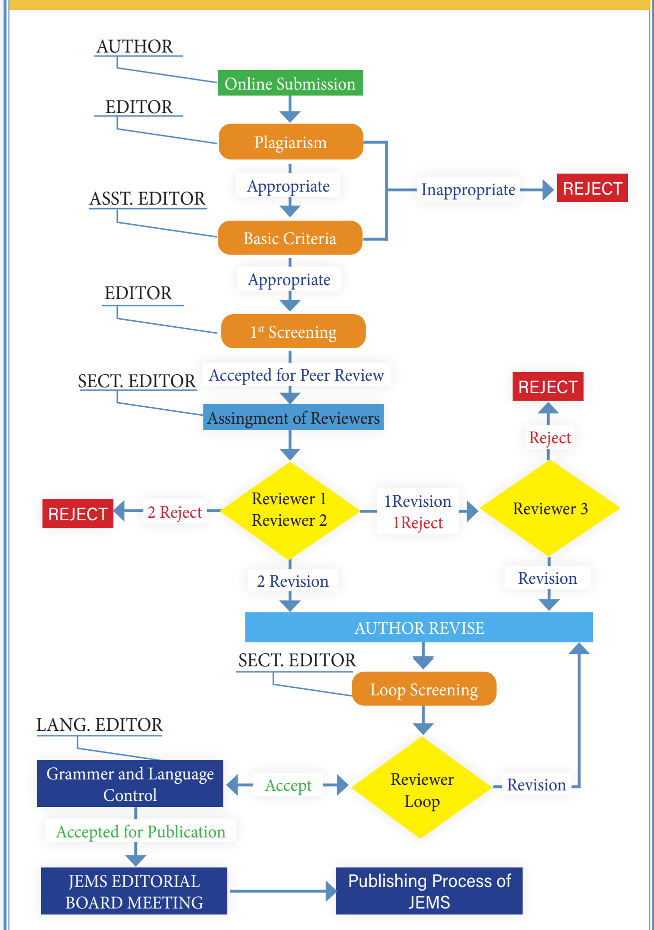

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Abstract

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Keywords: JEMS, Author, Manuscript, Guide

1. Introduction

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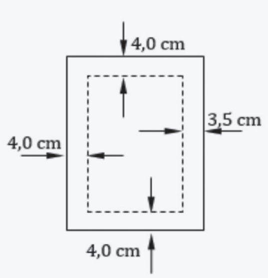

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Table 1. Sample Table

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

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

Average age: 28.624

Number of participants: 1,044 people

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

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Journal of ETA Maritime Science 2021;9(2):64-65

Transformation of Maritime Education into Distance Online Education

Selçuk Nas

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

Keywords

Maritime education, Distance online education, Simonline solution

We have started to experience a rapid transformation in maritime education, which has traditional principles and methodologies. The forcing of environmental factors and development in communication technologies have a remarkable role in this transformation. An environmental factor that has a large contribution in this change is the excessive demand for trained human power in maritime industry, which has increased during the pandemic. This increase was owing to the reluctance of seafarers to go to the ship during the pandemic because of concerns of not being able to return to their homes at the end of their contracts. However, educational institutions that remained closed during the pandemic were insufficient to meet the trained human power supply needed by the maritime industry. Despite being equipped with large capitals, the inability of these institutions to meet these needs has made their education systems and methodologies questionable. As a result, the maritime education system had to initiate its own transformation.

The transformation that started in maritime education has met some resistance. Although the education of seafarers is conducted under certain standards such as International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), the tendency to preserve its traditional structure and principles has always been strong. Doyen trainers in the traditional mindset argue that the face-to-face structure of maritime vocational education should be preserved. On one hand, ignoring traditionalists is not possible, especially concerning the attitude, behaviour development, and safety culture training of seafarers. On the other hand, discussions on distance education for developing technical skills continued before the pandemic. During the pandemic, the technological infrastructure of maritime education could be delivered to students who were isolated at home, which led to the transformation in traditional education methods. Towards the end of the COVID-19 pandemic process, the simulator-supported training infrastructure in maritime education started to be delivered to students in their homes with the developments in communication technologies and its usage has started in the service trainings on board ships.

With these developments in technology, the transformation in traditional education methodologies has become inevitable. Applications of distance online education methodologies that have recently started to develop and tried in maritime education systems have given us the opportunity to compare traditional methods with new ones. For this, the "Simonline Solution" results at Dokuz Eylül University Maritime Faculty were examined for advanced simulator-supported training given in the undergraduate seafarer's education, especially in the last years. In addition, the suitability of a curriculum aimed at team learning and skill development for distance online education was investigated using an advanced methodological approach in simulator-supported trainings. Considering the Simonline Solution results, if the distance online simulator supported trainings are conducted with the appropriate infrastructure, technology, methodology, resources, and guidance, the following advantages over the traditional method have been determined:

- 24/7 access to simulator systems by student teams.
- Teams can plan their own simulator run times.

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

- Opportunities provided by technology to validate acquired skills.
- Possibility of repeating the given tasks until the team succeeds.
- Awareness of being a team and helping each other among students.
- Benefit for the development of nontechnical skills
- Each team's simulation experience can be followed by other teams
- Ability to self-assess the team's skills and knowledge
- Increasing students' interest in the lesson.

The obligations and necessity are the only factors that break down prejudices and initiate transformations. From this point of view, the pandemic has provided an opportunity to try many untried things in human history with the help of technology. It destroyed prejudices and lit the fire that started many changes in maritime education. The International Maritime Organization (IMO), which is the global standard-setting authority of maritime education, is late in taking initiatives or undertaking a regulatory role in these matters.

Finally, we are pleased to introduce the JEMS 9 (2) to our valued followers. There are valuable and endeavoured studies in this issue of the journal. We hope that these studies will contribute to the maritime industry. I would like to mention my gratitude to authors who sent their valuable studies for this issue, to our reviewers, editorial board, section editors, and associate editors who provide quality publications by following our publication policies diligently. I would also like to express my thanks to LookUs Scientific and Galenos Publishing House who spent great efforts in the preparation of this issue.

Sincerely yours,

Prof. Dr. Selçuk NAS
Editor-in-Chief

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Journal of ETA Maritime Science 2021;9(2):66-73

The Impact of Uncertainty on National Port Throughput: Evidence From European Countries

Bayram Bilge Sağlam, Resul Tepe, Abdullah Açık

Dokuz Eylül University Maritime Faculty, Department of Maritime Business Administration, İzmir, Turkey

Abstract

This study investigates the effect of economic policy uncertainties on national port throughputs of selected European countries. For this purpose, we used quarterly observations of 21 European countries covering the periods between 2005 Q1 and 2018 Q3. The Granger non-causality test was used for heterogeneous panel data models and we found that economic policy uncertainties have a considerable impact on port throughputs in the selected sample. Causality tests on individual country level have shown that uncertainties in Belgium, Denmark, Finland, Ireland, Poland, Slovenia, Spain, and the United Kingdom have an influence over their port throughputs. Moreover, the present results show cross-sectional dependencies in uncertainty and port throughput variables, indicating that collaborative efforts by European nations are needed to avoid the risks associated with economic policy uncertainties due to the integrated structure of the countries.

Keywords

Economic policy uncertainty, Port throughput, Panel causality

1. Introduction

It is well known that economic policy uncertainties pose a challenge for the decision makers in the port industry because competition in this industry heavily depends on capital intensive investments [1]. Decision makers must seek ways to enhance competitiveness through investment projects that aim to expand capacity and productivity. However, carrying out these costly, extensive, and irreversible investment projects becomes difficult, especially when the market is under the influence of uncertainty [2]. To eliminate the risk of taking decisions that would lead to negative outcomes like congestions, idle capacities, and unproductivity, decision makers must understand the relationship between economic policy uncertainty and the performance of their businesses [3]. This relationship characteristic may vary in different countries of the world depending on the status of macroeconomic fundamentals [4]. Therefore, it is also important for decision makers to understand the uncertainty level of the market and that of the country in which they operate.

Uncertainty has become one of the prominent research topics in port economics due to its significant impact on management decisions. In this context, Lagoudis et al. [5] proposed a three-phase model to evaluate port investment strategies in uncertain environments. The model starts with an assessment of future uncertainties and is followed by an identification of investment strategies and their comparison. Linking the level of uncertainty with port capacity planning decisions, Balliauw et al. [6] identified real options models as a suitable method for investment project valuations and revealed how this method helps decision makers to determine the right size for their projects. Zheng and Negenborn [7] also used a real option approach to investigate timing decisions in terminal constructions by considering demand uncertainty. However, the related literature is not limited to the studies focused on the impact of uncertainty on investment decisions since the level of uncertainty affects many other managerial decisions in the port industry. For instance, Tovar and Wall [8] focused on demand uncertainty from a cost perspective and quantified the impact of demand changeability on port costs of Spanish

Address for Correspondence: Abdullah Açık, Dokuz Eylül University Maritime Faculty, Department of Maritime Business Administration, İzmir, Turkey
E-mail: abdullah.acik@deu.edu.tr
ORCID ID: orcid.org/0000-0003-4542-9831

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port authorities. The study of Satta et al. [9] focused on the relation between uncertain market conditions and the formation of interorganizational networks.

Despite the growing scientific interest in uncertainty in the port economics literature, answer to the basic question of "Does economic policy uncertainty have an impact on the port throughput (PT) of nations?" still remains vague. We believe that this question needs to be addressed with multi-country analysis, considering that economic policy uncertainty in every individual country may vary and spread to one another. Hence, the aim is to reveal both country-specific and general results, which will help decision makers in gaining a clearer understanding of the extent to which their ports' performances are influenced by the economic policy uncertainties of the countries in which they operate. From the port investment perspective, present findings would be helpful for the global terminal investors since the level of economic policy uncertainty in the targeted country is one of the most important macroeconomic indicators that need to be taken into account to ensure a predictable return of investment.

To reveal the link between economic policy uncertainty and PT, we use the data from world uncertainty index (WUI) for evaluating the economic policy uncertainty of selected European countries. WUI is developed by Ahir et al. [10], and it has become one of the highly preferred tools to manifest the uncertainty levels of countries in related literature. Gozgor et al. [11], linked economic uncertainty and domestic credits whereas Karabulut et al. [12] focused on the relationship between commodity prices and world trade uncertainty. These are the two examples that use data from WUI to assess the level of economic policy uncertainty. Until now, studies on uncertainty in the port economics literature have measured uncertainty with different scales. Using the WUI, which measures uncertainty with a standard structure for each country, allows these findings to compare with similar studies that can be conducted in the future. Besides the data from WUI, the present study evaluates the port performance of the selected countries using the cargo throughput data collected from Eurostat [13]. However, developments in one country are likely to affect other countries considering the integrated economic and political structure of European countries. In this context, we considered the causality analysis developed by Dumitrescu and Hurlin [14]. Unlike standard panel data analyzes, this method takes cross-sectional dependency (CD) and heterogeneity into account.

The rest of the paper is structured as follows: Section 2 explains the methodology of the study and presents the data analysis, which is followed by the results of the analysis (Section 3). Finally, the study concludes with a discussion of the findings of policy implications that need to be considered both by the port managers and national policymakers of international trade., limitations, and scope for future research (Section 4).

2. Data and Methodology

The causality analysis proposed by Dumitrescu and Hurlin [14] was considered for this work and the effects of uncertainty on port traffic in European countries were studied. This method fits well with the proposed study as it considers both CDs and heterogeneity. Information on the data that is used in the present model is given in the following section.

2.1. Data

The present dataset consists of 55 quarterly observations of 21 European countries and covers the period between 2005 Q1 and 2018 Q3. The selected countries are listed in alphabetical order as follows: Belgium, Bulgaria, Croatia, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Romania, Slovenia, Spain, Sweden, and United Kingdom. Cyprus, Estonia, and Malta are excluded from the sample since they are not included in the WUI list.

The PT variable shows the gross weight of goods handled in that country based on thousand tones. PT data of the European countries are obtained from Eurostat database [13]. Table 1 shows descriptive statistics on the PT. These statistics provide vital information to understand the position of each country in terms of PT in the sample. Skewness and kurtosis values provide information about the distribution of the variables. Symmetry of distribution can be interpreted by skewness and tail features by kurtosis. When the mean values of the cargo traffic of the ports are examined, the highest port traffic is observed in the Netherlands (135 million tons), and the lowest traffic is observed in Slovenia (4.3 million tons). This data reveals that the Netherlands is one of the main port centers for the European countries. Thus, the port outputs in the countries within the sample differ significantly.

The WUI has been developed by Ahir et al. [10]. They have formed quarterly indices for 143 countries starting in 1996 Q1 and used country reports of the Economist Intelligence Unit to develop the index. These reports include major political and economic developments and forecasts of economic policy conditions in each country. The WUI in the present study refers to the uncertainty score for the related country, and data for the variable is obtained from EPU [15]. Table 2 presents descriptive statistics of the data. These statistics are important for identifying different characteristics of the countries in the

Table 1. *Descriptive statistics of port throughputs*

Country	Mean	Median	Maximum	Minimum	Standard deviation	Skew.	Kurt.	Obs.
Belgium	58120.67	57623.00	69365.00	47613.00	4850.436	0.066971	2.643140	55
Bulgaria	6604.418	6544.000	9097.000	4184.000	1044.134	0.311602	3.075233	55
Croatia	4687.618	4667.000	6656.000	2883.000	923.2808	0.250518	2.529736	55
Denmark	21339.73	21161.00	25712.00	18347.00	1872.042	0.673074	2.696900	55
Finland	25769.58	25900.00	29051.00	20956.00	2126.894	-0.454541	2.429391	55
France	78149.25	76521.00	88589.00	70537.00	5195.252	0.598965	2.063264	55
Germany	73259.69	74256.00	82140.00	63002.00	4099.365	-0.656427	3.135955	55
Greece	33715.60	33229.00	44300.00	24897.00	5012.965	0.222002	2.247071	55
Ireland	11783.85	11739.00	13344.00	9070.000	827.7771	-0.516026	3.630215	55
Italy	119433.9	119293.0	142367.0	101780.0	9353.151	0.150467	2.302870	55
Latvia	15471.49	15237.00	19346.00	12151.00	1649.910	0.612387	2.877541	55
Lithuania	9687.709	9715.000	13252.00	6066.000	1930.050	-0.194043	2.199310	55
Netherlands	135614.1	137665.0	154711.0	112910.0	11763.06	-0.414230	2.074033	55
Norway	44753.04	45119.00	49820.00	37820.00	2524.495	-0.648840	3.326053	55
Poland	15375.49	15041.00	23328.00	10060.00	3015.649	0.584731	2.964100	55
Portugal	18199.91	17091.00	23816.00	13668.00	2882.460	0.590992	1.975018	55
Romania	10815.73	10754.00	14444.00	7826.000	1686.887	0.111477	2.095042	55
Slovenia	4305.909	4177.000	5979.000	2720.000	796.0325	0.242468	2.481617	55
Spain	105481.5	104682.0	128699.0	85952.00	9617.509	0.389028	2.932628	55
Sweden	41321.00	41943.00	46353.00	35428.00	2245.290	-0.462833	3.370118	55
United K.	127264.9	124214.0	145180.0	112724.0	9482.852	0.637866	2.031741	55
All	45769.29	25681.00	154711.0	2720.000	42884.17	0.966861	2.596443	1.155

Skew: Skewness value, Kurt: Kurtosis value

Source: Eurostat [13]

sample. The mean values show that the United Kingdom has the highest uncertainty (0.374) whereas Finland has the lowest uncertainty (0.118). The highest PT is about 30 times that of the lowest throughput whereas the highest uncertainty is about three times that of the lowest uncertainty. This situation can be interpreted as the uncertainty being experienced in a more commonly in the European countries.

2.2. Testing Cross Sectional Dependence and Homogeneity

Recent developments in panel data causality analysis highlighted two major econometric problems: Cross-sectional dependence and heterogeneity across the sample [16]. Due to international commercial relationships, and financial and economic integration, change in any country can easily be transferred to other countries [17]. Therefore, estimation results in cross sectionally dependent panel data are often inconsistent and upward biased [18]. Consequently, testing the cross-sectional condition is of great importance for panel causality analysis.

In this study, the lagrange multiplier (LM) test developed by Breusch and Pagan [19], CD and CD LM test developed by Pesaran [20], and LM adjusted test developed by Pesaran et al. [21] are used to check for CD. To compute the LM test, the following empirical model should be estimated (formula 1 is below):

$$y_{it} = a_i + \beta_i x_{it} + \mu_i \text{ for } i = 1, 2, 3, \ldots, N;\ t = 1, 2, \ldots, T \qquad (1)$$

Where i indicates cross-section dimension; t indicates time dimension; y_{it} is the dependent variable; x_{it} is a vector of independent ones; a_i and β_i indicate the individual intercepts and slope coefficients across the sample. The null hypothesis related to the absence of cross-sectional dependance is expressed as follows:

$H_0 : Cov(\mu_{it}, \mu_{jt}) = 0$ for all t and i ≠j

Table 2. *Descriptive statistics of uncertainty*

Country	Mean	Median	Maximum	Minimum	Standard deviation	Skew.	Kurt.	Obs.
Belgium	0.119096	0.097409	0.479004	0.000000	0.116151	1.066161	3.670711	55
Bulgaria	0.216541	0.167898	0.686048	0.000000	0.188498	0.938704	2.980879	55
Croatia	0.151772	0.115794	0.604804	0.000000	0.131944	1.207963	4.623405	55
Denmark	0.209118	0.142572	1.074460	0.000000	0.187795	2.006200	9.404350	55
Finland	0.118383	0.079321	0.551369	0.000000	0.131482	1.264972	4.290570	55
France	0.197174	0.170261	0.563825	0.000000	0.112011	0.939905	3.655537	55
Germany	0.197630	0.180554	0.928103	0.000000	0.172505	1.662998	7.614112	55
Greece	0.157499	0.094060	0.689070	0.000000	0.185962	1.146794	3.362287	55
Ireland	0.212636	0.210585	0.871903	0.000000	0.186782	1.015775	4.342964	55
Italy	0.225558	0.201518	0.667646	0.000000	0.180546	0.429957	2.205035	55
Latvia	0.171159	0.129626	0.488138	0.000000	0.126764	0.631897	2.700571	55
Lithuania	0.125517	0.113701	0.462168	0.000000	0.123813	0.895365	3.068519	55
Netherlands	0.196546	0.157381	0.756920	0.000000	0.188609	1.096425	3.779137	55
Norway	0.229331	0.205065	1.382685	0.000000	0.220483	2.847575	14.90800	55
Poland	0.234885	0.226638	0.917684	0.000000	0.184760	1.506098	6.001958	55
Portugal	0.184129	0.177788	0.591331	0.000000	0.140650	0.683845	3.146598	55
Romania	0.170079	0.120518	0.604047	0.000000	0.134684	1.089185	4.131570	55
Slovenia	0.170683	0.123548	0.698432	0.000000	0.171560	1.101345	4.007376	55
Spain	0.223278	0.194137	0.819001	0.000000	0.169433	0.875883	4.244637	55
Sweden	0.202967	0.158328	0.740101	0.000000	0.163471	0.887030	3.413207	55
United Kingdom	0.374340	0.322789	1.364153	0.000000	0.268698	1.674401	6.213444	55
All	0.194682	0.151872	1.382685	0.000000	0.176867	1.664019	8.334078	1.155

Skew: Skewness value, Kurt: Kurtosis value

Source: Economic Policy Uncertainty [15]

The alternative hypothesis that indicates cross-sectional dependence is expressed as follows:

$H_a: Cov(\mu_{it}, \mu_{jt}) \neq 0$ for at least one pair of i ≠j

The LM test for testing the null of cross-sectional dependence is introduced by Breusch and Pagan [19] as follows (formula 2 is below):

$$LM = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^2 \sim \chi^2_{N(N-1)/2} \qquad (2)$$

where $\hat{\rho}_{ij}$ indicates a pair-wise correlation of the residuals from equation (1) for each *i*. The LM test is effective when N is very small compared to T. Due to this limitation, Pesaran [20] suggested the structured type of LM test for large panels as (formula 3 is below):

$$CD_{lm} = \left(\frac{1}{N(N-1)}\right)^{1/2}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(T\hat{\rho}_{ij}^2 - 1) \sim N(0,1) \qquad (3)$$

However, when N is large and T is small, the CD_{lm} test is subject to size distortions. Hence, Pesaran [20] suggested a more valid CD test as (formula 4 is below):

$$CD = \sqrt{\left(\frac{2T}{N(N-1)}\right)}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}\right) \sim N(0,1) \qquad (4)$$

Pesaran et al. [21] indicated in further studies that power of the cross-sectional dependence test diminishes when the mean pair-wise correlation of the population is close to 0. Therefore, the authors suggested a bias-adjusted test by modifying the LM test. The improved test is as follows (formula 5 is below):

$$LM_{adj} = \sqrt{\left(\frac{2}{N(N-1)}\right)}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\frac{(T-k)\hat{\rho}_{ij}^2 - \mu_{Tij}}{\sqrt{v_{Tij}^2}} \sim N(0,1) \qquad (5)$$

The panel causality analysis used in the study can be applied both when cross-sectional dependencies exist or not. The cross-sectional dependence is also of great importance in selecting the unit root test preferred in the analysis. If there is no CD, the unit root tests described as first-generation are used; otherwise, second-generation unit roots are preferred.

If intense cross-sectional dependence is a concern, every country in the sample may have similar economic activity structures. Hence, assuming slope homogeneity may lead to illusive estimates when the structure of the panel becomes heterogeneous [22]. Pesaran and Yamagata [23] developed one of the most widely used tests for the null hypothesis of homogeneity, called as Delta test. At first, an improved type of Swamy test is calculated as follows (formula 6 is below):

$$\tilde{S} = \sum_{i=1}^{N} \left(\tilde{\beta}_i - \tilde{\beta}_{WFE}\right)' \frac{x_i' M_T x_i}{\tilde{\sigma}_i^2} \left(\tilde{\beta}_i - \tilde{\beta}_{WFE}\right) \tag{6}$$

Where $\tilde{\beta}_i$ indicates pooled OLS; $\tilde{\beta}_{WFE}$ indicates the weighted fixed effect estimation of the first equation; M_T indicates identity matrix of order T; $\tilde{\sigma}_i^2$ indicates the estimator of σ_i^2. For the test statistics, the following equation is computed (formula 7 is below):

$$\tilde{\Delta} = \sqrt{N}\left(\frac{N^{-1}\tilde{S} - k}{\sqrt{2k(T-k-1)/T+1}}\right) \sim N(0,1) \tag{7}$$

All the mentioned cross-sectional dependence tests and homogeneity tests are applied to the data set, and the following steps are structured based on CD results.

2.3. Testing Unit Root

The method proposed by Dumitrescu and Hurlin [14] requires stationary data. Considering the outcomes of the cross-sectional dependence and homogeneity tests, Smith et al. [24] proposed the Bootstrap-IPS (Im, Pesaran, Shin) test to determine integration properties of PT and the WUI. The unit root test is an improved type of test developed by Im et al. [25] and considers the cross-sectional dependence into account using bootstrap blocks.

In the unit root test suggested by IPS [25], the augmented Dickey-Fuller (ADF) test is implemented to the individual series, which is computed as follows (formula 8 is below):

$$\Delta y_{i,t} = \alpha_i + \beta_i y_{i,t-1} + \sum_{j=1}^{pi} \rho_{i,j} \Delta y_{i,t-j} + \gamma_{it} + \varepsilon_{i,t} \tag{8}$$

Then statistics for IPS is calculated by considering the mean of the individual statistics of ADF as follows (formula 9 is below):

$$t_{NT} = \frac{1}{N}\sum_{t=1}^{N} t_{iT}(p_i) \tag{9}$$

IPS proposes the uses of the standardized statistic as shown, by assuming that cross-sections are independent (formula 10 is below):

$$t_b = \frac{\sqrt{N}(t_{NT}) - E(t_T)}{\sqrt{Var}(t_T)} \tag{10}$$

The Bootstrap-IPS test developed by Smith et al. [24] is the bootstrap version of the IPS [25] and considers cross-sectional dependence across countries. The null hypotheses of these tests point to the unit root, and if the unit root is detected, differences in the series are included in the panel Granger causality method.

2.4. Panel Granger Causality Test

In this research, we preferred to apply panel causality analysis facilitating the modeling of cross-sections, which yield effective results even for short time periods as the number of observations is high [26]. The method developed by Dumitrescu and Hurlin [14] is used in this study based on the panel causality tests. In this method, assumption related to the difference of all coefficients across cross-sections makes the method more reliable and robust than traditional Granger tests [27]. Thus, heterogeneity in the data set is considered. Besides, the T>N constraint, which is a requirement of some other panel causality tests such as Emirmahmutoglu and Kose [28], has also disappeared in the Dumitrescu and Hurlin [14] approach [29]. Finally, in Europe, which has an integrated economic structure, the shocks seen in one country will spread to other ones. In this respect, the method we have chosen can be applied against this situation since it also takes the possible CD into account.

This method must be used with stationary variables having fixed coefficients in vector autoregressive structure [27].

Dumitrescu and Hurlin [14] predicated the stationary fixed-effects panel equation for non-homogeneous panels as follows (formula 11 is below):

$$\Delta P_{i,t} = a_i + \sum_{k=1}^{K} y_i^k \Delta P_{i,t-k} + \sum_{k=1}^{K} \beta_i^k UI_{i,t-k} + \varepsilon_{i,t} \tag{11}$$

Where Δ is the difference operator; P is the log of PT; UI is the log of uncertainty index for country i (i=1, 2,…N) in period; t, γ, and β are parameters that change across countries; ε are residuals. As a result of this analysis, both individual causality results and panel causality results are obtained in two directions: from uncertainty to port and port to uncertainty.

3. Results

The LM test developed by Breusch and Pagan [19], CD and CD LM test developed by Pesaran [20], and LM adjusted test developed by Pesaran et al. [21] were all applied to test the cross-sectional dependence in the data and model. Table 3 presents the results. The null hypothesis of these tests indicates no cross-sectional dependence. LM, CD, and LM adjusted tests are generally used for T>N cases whereas the first two reject the null hypothesis for the WUI variable. Delta test indicated that the null hypothesis of homogeneity could not be rejected for the variable. For the PT variable, the null hypotheses were rejected in both cross-sectional dependence and homogeneity tests. In the test results applied for the model, both null hypotheses are rejected. Based on these results, it was determined that unit root tests defined as the second generation were necessary to check the stationary and causality method suggested by Dumitrescu and Hurlin [14].

For the causality method developed by Dumitrescu and Hurlin [14], the series must be stationary. Thus, considering the dependence of the cross-sections in the series, the Bootstrap-IPS unit root test was implemented on the variables, and subsequent results are shown in Table 4. To calculate the critical values, the initial values are 50 for block size, 6 for maximum lags, and 1000 for the number of bootstrap replications. Based on the results, the WUI variable is stationary, and the null of unit root hypothesis for the PT cannot be rejected. Thus, the analysis was continued using the first difference of the PT.

Table 3. *Results of the pre-tests before causality analysis*

Test	WUI	PT	Model
LM	247.484 [0.039]	443.62 [0.000]	2393.466 [0.000]
CD LM	1.829 [0.034]	11.400 [0.000]	106.542 [0.000]
CD	-4.798 [0.000]	-1.176 [0.000]	25.602 [0.000]
LM Adj.	0.265 [0.395]	33.345 [0.000]	6.159 [0.000]
Delta	0.667 [0.252]	5.054 [0.000]	2.195 [0.014]
Delta Adj.	0.686 [0.246]	5.198 [0.000]	2.256 [0.012]

Probability values are shown within parenthesis

LM: Lagrange multiplier, CD: Cross-sectional dependency, WUI: World uncertainty index, PT: Port throughput

GAUSS statistical software was used to apply the panel causality analysis proposed by Dumitrescu and Hurlin [14]. Since the data set consists of quarterly observations, the number of lags is selected as 6. To find the most appropriate lag, the Akaike information criterion was selected. According to the results, significant causalities from WUI to PT were obtained based on individual countries and panels. Individual results indicated that uncertainties in Belgium, Denmark, Finland, Ireland, Poland, Slovenia, Spain, and the United Kingdom affect their PTs. However, cargo traffic in ports does not affect uncertainty in the countries [5].

4. Conclusion and Policy Implications

This study has focused on the relationship between economic policy uncertainty and PT in the context of European countries. Unlike the current literature on port economics, we used the data gathered from WUI to reflect country-specific uncertainty levels. Therefore, problems related to the unstandardized measurement of uncertainty in countries are minimized since macroeconomic indicators in each country may have different characteristics.

The analysis provided empirical results revealing the significant impact of uncertainty on throughputs of European ports. Moreover, the present results indicate that both the cargo traffic of ports and uncertainties of the countries have cross-sectional dependence showing that the changes experienced by any of the European countries affect other countries as well. This finding can be explained by the integrated nature of European economics and policy. Hence, these results highlight the need for collaborative efforts by European nations to avoid the risks associated with economic policy uncertainties.

We believe that the present results will be useful to the European policy makers as well as port investors. Since port investments are costly investments that require decision making in the long term, uncertainty in the investment environment should be low and financial

Table 4. *Bootstrap-IPS test results*

	Level				First difference			
	PT		WUI		PT		WUI	
	C	C&T	C	C&T	C	C&T	C	C&T
t-bar statistics	-1.470 [0.484]	-2.169 [0.353]	-4.162 [0.000]	-4.508 [0.000]	-5.136 [0.000]	-5.210 [0.000]	-6.713 [0.000]	-6.716 [0.000]

Probability values are shown within parenthesis.

WUI: World uncertainty index, PT: Port throughput, C: Constant, C&T: Constant and trend

Table 5. *Bivariate causality test results*

	(1) From WUI to PT			(2) From PT to WUI		
Country	**Lag**	**Wald**	**Prob.**	**Lag**	**Wald**	**Prob.**
Belgium	1.000	23.942	0.000	1.000	0.298	0.585
Bulgaria	3.000	0.501	0.919	3.000	0.602	0.896
Croatia	3.000	0.771	0.856	3.000	4.571	0.206
Denmark	3.000	10.124	0.018	3.000	2.133	0.545
Finland	4.000	10.693	0.030	4.000	3.077	0.545
France	2.000	1.982	0.371	2.000	3.110	0.211
Germany	3.000	5.746	0.125	3.000	2.940	0.401
Greece	4.000	4.719	0.317	4.000	5.425	0.246
Ireland	4.000	10.645	0.031	4.000	0.883	0.927
Italy	4.000	5.901	0.207	4.000	4.013	0.404
Latvia	2.000	3.327	0.190	2.000	4.098	0.129
Lithuania	6.000	5.282	0.508	6.000	8.721	0.190
Netherlands	4.000	2.958	0.565	4.000	7.376	0.117
Norway	4.000	6.133	0.189	4.000	1.576	0.813
Poland	6.000	19.032	0.004	6.000	6.379	0.382
Portugal	3.000	3.863	0.277	3.000	0.606	0.895
Romania	3.000	2.525	0.471	3.000	0.271	0.965
Slovenia	6.000	11.459	0.075	6.000	8.823	0.184
Spain	2.000	6.118	0.047	2.000	0.776	0.678
Sweden	6.000	9.348	0.155	6.000	9.349	0.155
United Kingdom	2.000	13.643	0.001	2.000	1.456	0.483
Panel Z_NT		6.835	0.000		1.121	0.904

Bootstrapped CVs for (1): 2.097 (10%), 2.634 (5%), 3.949 (1%); Bootstrapped CVs for (2): 1.852 (10%), 2.461 (5%), 3.559 (1%)
WUI: World uncertainty index, PT: Port throughput

returns should be predictable in the long term. Our results also explain how port managers in each country should consider uncertainty as a factor influencing investment decisions since the relationship between uncertainty and PT varies in different countries. Thus, ports operating in countries where the impact of uncertainty is significant may have to work harder to implement flexible and agile solutions.

Due to the increasing interdependence in world economies, the economic policy uncertainty has become a determining factor in port business due to its ties with international trade. Especially, heightened economic tensions between China and the United States and growth in protectionism are the two most important events that increase uncertainty and risks in the maritime trade environment. The decision of the United Kingdom and Northern Ireland to leave the European Union (Brexit) has had a relatively small impact on global maritime trade so far; however, it remains a threat for the future. The effects of the global pandemic that emerged in 2019 and spread to the world in 2020, will also be seen more clearly in the near future. In such an environment, where decisions made by any economic or political actor can quickly affect others, there is only one consequence, and that is uncertainty. In a competitive environment where uncertainty is so decisive, it is necessary to perceive changes quickly, make the counter move, and do this with as flexible decision processes as possible. In this respect, future research should focus on the ongoing influence of economic policy uncertainty, resulting in the aforementioned current events on international trade in general and port management in particular.

Our study has certain limitations that can be addressed in future research. The true nature of the relationship between uncertainty and port performance needs to be evaluated by increasing the sample size. Another limitation is the availability of the PT data. While the WUI published data from 1996 to date, PT data obtained from Eurostat does not provide data before 2005. This mismatch in the dataset compelled us to carry out our research on a relatively limited time period.

Authorship Contributions

Concept design: B.B. Sağlam, R. Tepe, A. Açık, Data Collection or Processing: B.B. Sağlam, R. Tepe, A. Açık, Analysis or Interpretation: B.B. Sağlam, R. Tepe, A. Açık, Literature Review: B.B. Sağlam, R. Tepe, Writing, Reviewing and Editing: B.B. Sağlam, R. Tepe.

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Estimation of Probabilistic Seismic Hazard for Marine Structures: A Case Study for Haydarpaşa Port

Aydın Mert

Boğaziçi University, Kandilli Observatory and Earthquake Research Institute, Department of Earthquake Engineering, İstanbul, Turkey

Abstract

The size and importance of maritime transportation in world trade are well known. The number of ports, which is one of the most important elements of maritime transportation, is increasing day by day not only in our country but also throughout the world. Many active fault systems in our country are located at sea. In the Marmara Region in particular, most active branches of the North Anatolian Fault system pass through the Sea of Marmara. When offshore structures such as ports are constructed in high-seismicity zones such as the Sea of Marmara, conducting site-specific seismic hazard studies is necessary to reduce the seismic risk of offshore structures. In 2007, the first Turkish Seismic Design Code for Port Structures was published, which introduced new design concepts in the seismic design of offshore structures. According to this code, the design can be finalized in three basic steps: assessment of regional seismicity, estimation of geotechnical hazards, and soil-structure interaction analysis of offshore structures. Nowadays, the first Turkish Seismic Design Code for Port Structures is on the verge of a major update, which was published as a draft report in May 2019. In this manuscript, site-specific probabilistic seismic hazard analysis is needed to determine the seismic hazard associated with typical port sites. Considering this new draft code as a guideline document, we developed consistent seismic hazard studies for offshore structures within the Haydarpaşa Port sites. Unlike the old one, this new document identifies four different levels of ground motion: minimum damage level earthquake (T_R=72), limited damage level earthquake (T_R=144), controlling damage level earthquake (T_R=475), and maximum considered earthquake (T_R=2.475).

Keywords

Probabilistic seismic hazard assessment, Marine structures, Uniform hazard spectra

1. Introduction

Most developed countries depend on the smooth functioning of their maritime ports. These ports are essential elements of the complete delivery system, and billions of tons of cargo are handled by ports, thus reflecting that international trade moves by water. Ports also play an important role in providing social, health, safety, and environmental benefits. Any serious or major deterioration or disintegration of these services because of a disaster such as an earthquake or earthquake-induced tsunami or landslides can be the cause of extreme losses across a wide range of socially valued activities and may considerably affect the economic conditions, security, and overall welfare of society.

An earthquake epicenter located close to marine structures or seaports is a direct threat. These marine structures are then exposed to the destructive influence of different levels of earthquakes, which can have disastrous or even catastrophic consequences. Such a natural event can also cause any level of indirect damage to marine structures. Stability and/or integrity problems can become an important risk factor for the marine structures because of strong ground motion or liquefaction. Many catastrophic earthquakes have occurred in recent history; thus, these risks are a reality not only in our country but also in many developed countries with high seismic zones (e.g., Hokkaido-Nansei-Oki, Japan, 1993; Hyogoken-Nanbu, Japan, 1995;

Address for Correspondence: Aydın Mert, Boğaziçi University, Kandilli Observatory and Earthquake Research Institute, Department of Earthquake Engineering, İstanbul, Turkey
E-mail: mertay@boun.edu.tr
ORCID ID: orcid.org/0000-0003-0762-6658

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Izmit, Turkey, 1999; Duzce, Turkey, 1999). During these earthquakes, many different marine structures suffer severe damage due to strong shaking of the ground or liquefaction.

The 1993 Hokkaido-Nansei-Oki earthquake caused an estimated economic loss of 13 billion yen in port structures [1]. A handbook was published [2] to describe the proposed methods for evaluating potential liquefaction and the possible preventive methods. The Hyogoken-Nanbu (Kobe) earthquake resulted in an estimated loss of 590 billion yen because of port damage [1]. Thus, a performance-based seismic design concept is introduced as a procedure in which two levels of earthquake motions were specified for design purposes.

After two devastating earthquakes in 1999-the Izmit earthquake on August 17 (M_w=7.4) and the Düzce earthquake on November 12 (M_w=7.2)-many articles and technical documents related to marine structure damages were written. Boulanger et al. [3] classified the structural damages in offshore structures and investigated the real performance of marine ports in a special volume of the journal Earthquake Spectra, which focused on the performance of all structures during these two earthquakes. Gunbak et al. [4] studied a relatively comprehensive list of damage to more than 20 marine structures. Yüksel et al. [5] studied in detail the extent of the damage to marine structures caused by the Kocaeli earthquake. Sumer et al. [6] provided an inventory of damages to marine structures as a result of soil liquefaction. After these catastrophic earthquakes, the General Directorate for Construction of Railways, Harbors, and Airports (RHA) of the Ministry of Transportation of the Turkish Republic organized a commission to prepare a seismic design code in 2005. This commission completed the first seismic design code, which is introduced the performance-based design concept for transportation structures, in the 2007 RHA seismic code [7].

Although the structural distance to fault rupture is at least 20 km, soil liquefaction and the generated extensive soil deformations caused serious damage to marine structures during January 12, 2010, earthquake in Port-au-Prince, Haiti. Similarly, during the M 8.8 Maule earthquake (February 27, 2010) in Chile, liquefaction induced ground failures and warped waterfront structures. The M 7.8 Kaikoura earthquake in New Zealand (2016) excited extensive soil liquefaction and large failure surfaces in the ground at Centre Port, Wellington, eventually causing widespread damage not only to wharves but also to seaport facilities [8].

One of the main purposes of this article is to draw attention to seismic risks in Turkish ports and the size of the losses they may cause. Seismic hazard refers to the level of ground shaking that can cause damage or any other secondary effects such as soil liquefaction and landslides at the Earth's surface due to earthquake activity at a given site in a given period. The relationship between ground motion values and their annual probabilities of exceedance is presented as an output of a seismic hazard assessment.

Evidently, any marine structure located in an active earthquake region should deal with seismic risk management studies. By definition, seismic risk can be interpreted as the anticipated losses as a result of earthquake-induced phenomenon. With the aim of developing proper studies in the field of seismic risk management and to contribute to decision-making processes, this work primarily focuses on site-specific probabilistic seismic hazard analysis of the Haydarpaşa Port site based on the New Turkish Seismic Design Code for Port Structures (NTSDCforPS) (Final report base draft report, interim report-3) [9].

RHA has a seismic code that was prepared in 2007. The code introduced performance-based design objectives for the first time for offshore structures in Turkey. In 2012, the Ministry of Transportation updated the RHA seismic code and organized a group of experts; NTSDCforPS is a product of this decision [7,9]. In this manuscript, all evaluations were made considering the final report basis draft report, interim report-3 (May 2019), which is used as a guide for the Turkish Seismic Code for the Constructions of Harbor and Coastal Structures.

2. Study Area

A probabilistic earthquake assessment study to obtain the uniform hazard curve for four different levels of ground motion is conducted by concentrating on Haydarpaşa Port in İstanbul. İstanbul is heavily populated, with more than 15.5 million people [10]. It is located in the Marmara Region in the northwestern part of Turkey and produces more than 31% of the country's grand national product [10]. Consistent with the economic importance of İstanbul, the city has several commercial ports. Haydarpaşa Port is the largest and oldest container port not only in İstanbul but also in the Marmara Region and is the third largest port in the nation.

The port consists of containers for handling and storing general cargo and ro-ro handlings. The short- and long-distance passenger transfers and urban transportation (maritime, railway, and highway) are other main components of the port [13]. The location and general layout of the port are demonstrated in Figure 1, which shows that the Haydarpaşa Port is located close (less than 20 km) to the northern branch of the North Anatolian Fault (NAF) system, which crosses the Sea of Marmara.

Another important issue is related to the study area, especially after the two catastrophic earthquakes in 1999. The entire Sea of Marmara has been identified as a seismic gap in most scientific papers [14]. This scientific reality is one of the reasons we select the Haydarpaşa Port as a study area.

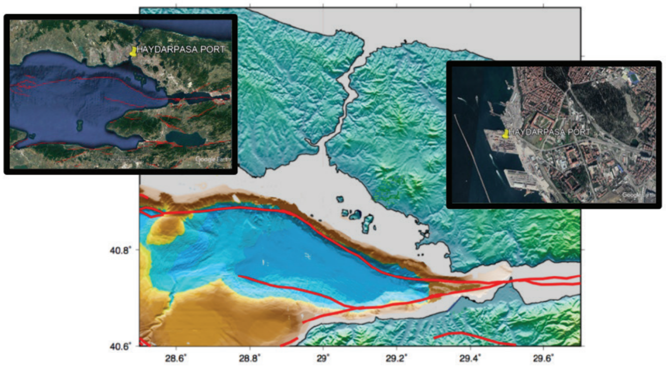

Figure 1. *Fault map and bathymetry of Marmara Sea together with the location of the Haydarpaşa Port (Bathymetric data based on Kandilli Observatory and Earthquake Research Institute (KOERI) [11] database, Numeric fault model based on Armijo et al. [12]).*

3. Methodology

One important difference between the RHA seismic code and the NTSDCforPS is that the latter requires design supervision and control services in some specific fields [7,9]. In the evaluation and design processes during the implementation of this regulation, design supervision and control services that require the special expertise of civil engineers are compulsory. These engineers must have theoretical and professional knowledge and experience in the relevant field to work in all relevant design stages from the beginning to the end of the project. According to NTSDCforPS [9], site-specific earthquake hazard calculations and earthquake ground motion in time domain fields are subject to design supervision and control services.

Coastal structures are divided into three main classes in terms of use, performance and severity levels expected during and after an earthquake. These classes are presented below.

Important Structures

- Have strategic importance in terms of security/defense
- Ensures rapid response and evacuation actions
- For toxic, flammable, or explosive materials
- Difficult, expensive, and indispensable after an earthquake

Normal Structures

- Structures that are not classified as important and simple structures

Simple Structures

- Structures that can be easily rebuilt after the earthquake
- Structures that can be considered to be extensively damaged after severe earthquakes
- Coastal fortifications

On the basis of this document, the design of new marine structures or evaluating existing marine structures under the effects of an earthquake is explained in chapter 2. RHA seismic code defines three different levels of earthquakes, whereas NTSDCforPS requires four different levels of earthquake ground motions [7,9].

(E-1) Earthquake Level

Very rare earthquake ground motions, with a 2% probability of exceedance (PofE) in 50 years, which probabilistically corresponds to a return period (T_R) of 2,475 years.

(E-2) Earthquake Level

Rare earthquake ground motions, with a 10% PofE in 50 years, T_R=475 years.

(E-2-A) Earthquake Level

Relatively frequent earthquake ground motions, with a 50% PofE in 30 years, T_R=144 years.

(E-3) Earthquake Level

Frequent earthquake ground motions, with a 50% PofE in 50 years, T_R=72 years.

To identify the classification of the calculation and evaluation methods to be applied, earthquake design classes (EDC) need to be determined, which is based on the coefficient of design spectral acceleration (SA) of the short period defined for DD-2 earthquake ground motion level.

EDC=4 $S_{DS}<0.33$

EDC=3 $0.33\leq S_{DS}<0.50$

EDC=2 $0.50\leq S_{DS}<0.75$

EDC=1 $S_{DS}\leq 0.75$

The seismic performance of port structures is based on the expected earthquake damage. These performance levels (PL) have four categories.

- Minimum damage (MD) PL
- Limited damage (LD) PL
- Controlled damage (CD) PL
- Collapse prevention (CP) PL

3.1. Probabilistic Seismic Hazard Assessment

The probabilistic seismic hazard assessment (PSHA) procedure depends on identifying the occurrence of an earthquake as a homogeneous Poisson's distribution and the evaluation of ground motion parameters such as peak ground acceleration (PGA) in a predetermined site from ground motion prediction equations. PSHA was introduced by Cornell [15] and further developed by contributions from McGuire [16].

The fundamental contents of the basic seismic hazard assessment procedure can be explained as follows:

Seismic source modeling: This comprises identification of possible seismic sources considering the geological and tectonic systems of the region and the properties of the geometric definition of the seismic source zones (such as area and line sources).

Frequency-magnitude relationship: The seismicity rate for all of the identified seismic sources is characterized by means of recurrence relationships. The magnitude distribution relationship developed by Gutenberg and Richter [17] is used in most studies.

Ground motion prediction equation: The ground motion prediction equation is generally used to predict the decrease in ground motion, which depends on the earthquake magnitude and source-to-site distance considering site geological conditions.

Computations of the seismic hazard can be identified by the following equation, which is an application of the total probability theorem (formula 1 is below):

$$H(a) = \sum_i V_i \iint P[A > a|m,r] f_{M_J}(m) f_{R|M_J}(r,m) dr dm \quad (1)$$

In this equation, the hazard H (a) represents the annual frequency of the earthquakes that produce a ground motion of amplitude A with a value higher than a. The amplitude A may represent PGA, velocity, or displacement, or it may represent the spectral pseudo-acceleration for a given frequency.

The summation in Equation 1 includes all sources; n*i* represents the annual rate of earthquakes (of a magnitude higher than some threshold values *Moi*) in a source *I*. *fMi* (*m*) and *fRi*|*Mi* (*r*;*m*) represent the probability density functions based on the magnitude and distance between different locations within the source i and the site in question, respectively. P (A>a|m, r) is the possibility that an earthquake with a magnitude m at a distance r can yield a ground motion with amplitude A at the specific site that is higher than a.

Seismic sources may be either faults or area sources. The source geometries and the calculation of *fRi*|*Mi* are specified differently for these two types of sources.

For fault sources, the common form for calculating P (A>a|m, r) is as follows:

$$\mathbf{ln}\, A = C_1 + C_2 M + C_3 \boldsymbol{ln} R + C_4 R + \varepsilon; \qquad \varepsilon \approx N(0, \sigma_\varepsilon^2) \quad (2)$$

where R is some measure of distance to the earthquake rupture. For area sources, the general form for calculating P (A>a|m, r) is

$$\mathbf{ln}\, A = C_1 + C_2 M + C_3 \mathbf{ln}\,(R + RZEROA) + C_4 R + \varepsilon; \qquad \varepsilon \approx N(0, \sigma_\varepsilon^2) \quad (3)$$

where R is the focal distance (assuming a point source), which is computed from the horizontal distance and the source depth h. In the above two equations, *C1, C2, C3, C4,* and *RZEROA* are constants, independent of *M* and *R*.

Either of the above two equations can be transformed into

$$\sum_i P[A > a/m\,, r] = \phi^* \left(\frac{lna - lnA(m,r)}{\sigma_\zeta} \right) \quad (4)$$

in which ϕ is the normal complementary cumulative distribution function and ln A (m,r) is the value of ln A obtained from Equation 2 or 3 by setting ε = 0.

The distribution of magnitude is generally assumed to be doubly truncated exponential, i.e.,

$$f_{Mj}(m) = k_i \beta_i exp[\beta_i (m = M_{0i})], \quad M_{0i} \le m \le M_{maxi} \quad (5)$$

in which k_i = (1- $exp\left[\beta_i\left(m\ =\ M_{0i}\right)\right]$-1 is a normalizing constant, M_{0i} is the threshold magnitude defined earlier, and M_{maxi} is the largest magnitude that may occur in the source.

3.2. Seismotectonic System and Seismicity of the Region

The Marmara Region is situated in a transition zone between the right-lateral strike-slip character of NAF and N-S extensional regime of the Aegean Region, which is why it has a complex and heterogeneous fault system together with high seismic activity (Barka and Kandinsky-Cade [18]; Dewey and Şengör [19]; Şengör et al. [20]; Orgulu [21]). The Sea of Marmara is known as a seismic gap along the NAF (Pınar [22]; Toksöz et al. [23]; Pondard et al. [24]; Şengör et al. [25]).

Historical records over more than 2,000 years in the Marmara Region show that the region is frequently exposed to strong shaking, experiencing many different catastrophic earthquakes or earthquake-induced landslides and tsunamis; these disasters may continue to occur in the future [26-28]. During the historical period (from 0 to 1900), about 600 earthquakes were identified in this region, with at least 38 of them being comparatively large shocks with a magnitude $M_s \geq 6.8$ [29] (Figure 2).

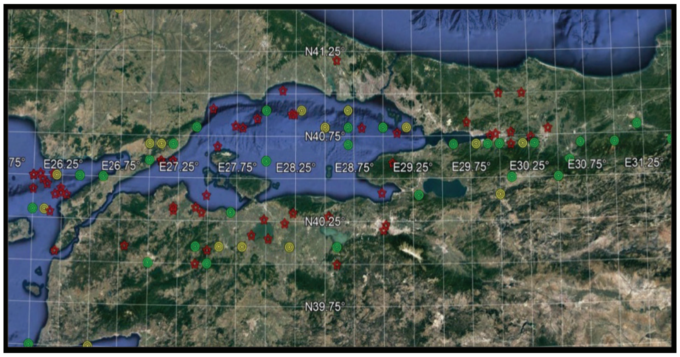

Figure 2. *Marmara Region earthquakes during 32 AD-2002 according to Ambraseys, 2002. Yellow and green circles demonstrate M≥6 and M≥7 earthquakes respectively during 32 AD-1900 (Ambraseys [26]). The red stars represent 5≤M≤ 7.6 earthquakes during 1900-2020*

Seismicity during the instrumental period (after 1900) and recent detailed micro-earthquake studies verify the same fact. During the instrumental period, earthquake activity within the region of the Sea of Marmara can be determined as a swarm-type activity (Figure 3). Using earthquake catalogs that contain earthquake records from historical and instrumental periods, Kalkan et al. [30] demonstrated the distribution of all evident events that are equal to or higher than magnitude 6 after the year 1500. A total of 36 events occurred, and seven of them are larger than magnitude 7 (M≥7.0). The most remarkable fact is that seven of the earthquakes with a magnitude higher than 7 (M≥7.0) occurred during the last century.

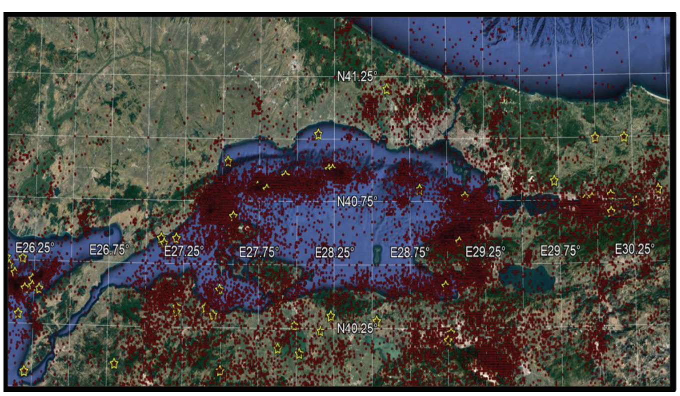

Figure 3. *Marmara Region earthquakes during 1900-2021 time period observed by Kandilli Observatory and Earthquake Research Institute (KOERI). Red Circles 1.0≤M≤4.0 earthquakes and yellow stars 5≤M≤7.5 earthquakes based on KOERI data. Symbol sizes are comparable to the earthquake magnitude*

3.3. Definition of Seismic Sources Modeling

The seismic source model is evaluated depending on the spatial distribution of earthquakes, regional tectonic structure, and deformational patterns. These earthquakes were collected and processed from the KOERI [11] catalog, which is composed of reported instrumental events (Mb≥3) covering the period from May 12, 1901, to July 31, 2015 (a total of 4,044 events). The following attributes for each event were collected: date, origin time, latitude and longitude, depth, and available reported magnitudes (i.e., mainly Mb). The catalog was investigated for duplication, completeness, and time independency of event distribution to achieve the objectives of this study. A basic assumption of our seismic hazard methodology is that earthquake sources are time independent (i.e., random distribution in time). Thus, catalogs must be free of dependent events such as foreshocks and aftershocks; this process often called declustering. We applied the procedure of Gardner and Knopoff [31] to eliminate foreshocks and aftershocks from the catalog.

Figure 4 shows the proposed seismic source model for the region. It is composed of 12 fault sources and three different rupture combinations (Table 1). For these fault sources, we used the characteristic earthquake model with slip rate based on regression analysis to calculate the magnitude-length relationship [32]. To consider fault slip rate, we followed the equation developed by Anderson et al. [33]. We also consider regional GPS studies to determine or to control fault slip rates.

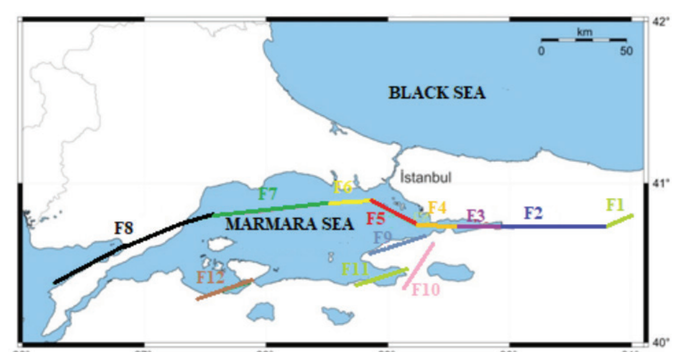

Figure 4. *Proposed seismic source model for Marmara Region*

In addition to these line sources, we used four major regional area seismic zones to reflect the background seismicity within the investigated region (Figure 5). For these area sources, we calculated some statistical parameters, such as the completeness magnitude (M_c) based on the maximum curvature method [34]. and seismicity of a region (the values of a and b are determined from the frequency magnitude distribution).

For a forecasting experiment similar to this study, the completeness of a catalog is one of the important factors

Table 1. *Fault segmentation information used in this study and shown in Figure 4. Name of the fault, style of faulting, and min/max magnitude*

Fault segment	Name of the segment	Mechanism	Slip rate	Beta	M_{min}	M_{max}
F1	Karadere	SS	25	1.84	7.1	7.3
F2	Sapanca	SS/NC	25	1.84	7.1	7.3
F3	İzmit	SS	25	1.84	7.1	7.3
F2-F3			25	1.84	7.3	7.5
F4	Hersek	SS	25	1.84	7.1	7.3
F2-F3-F4			25	1.84	7.5	7.7
F5	Adalar	SS	27	1.84	7.2	7.3
F6	Küçükçekmece	SS	25	1.84	7.1	7.3
F7	Orta Marmara	SS	25	1.84	7.1	7.3
F5-F6-F7			25	1.84	7.5	7.7
F8	Ganos	SS	25	1.84	7.3	7.5
F9	Çınarcık	SS	25	1.84	7.1	7.3
F10	Armutlu	SS	25	2.0723	6.4	6.6
F11	Gemlik	SS	25	2.0723	7.1	7.3
F12	Erdek	SS	25	1.9342	7.1	7.3
min: Mininmum, max: Maximum						

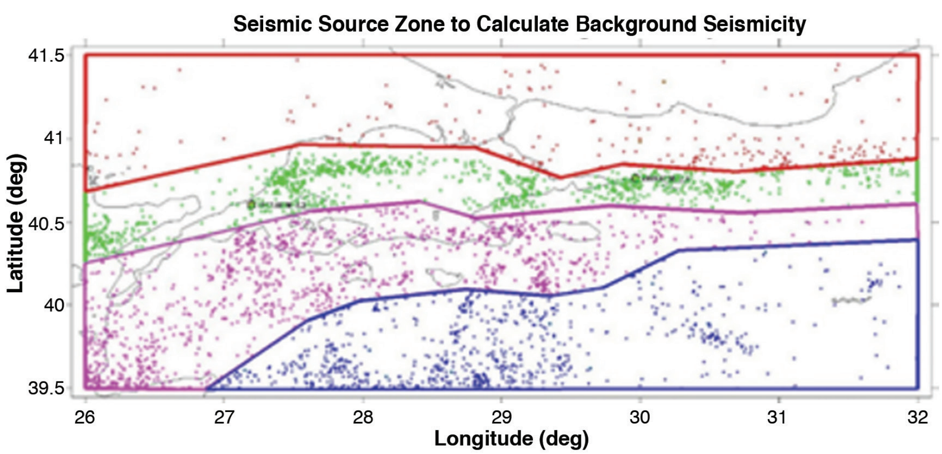

Figure 5. *Major regional area seismic zones to reflect background seismicity*

because various models require a full catalog to evaluate their parameters accurately. The minimum magnitude of the full catalog, (M_c), is another crucial parameter for seismicity studies. The number of seismographs increases daily all over the world and the analysis procedure improves; thus, (M_c) changes-usually in a decreasing manner-with time in most catalogs.

3.4. Magnitude Recurrence Relationship

A catalog with complete earthquake data is essential for the accurate calculation of PSHA. In this study, the magnitude of completeness (M_c) was determined based on the maximum curvature method [34]. The a-value and the b-value are assigned by using the distribution of frequency magnitude for four regional area seismic zones. These results are summarized in Table 2. The a-value is the value where the line intercepts the y-axis, and the b-value is the inclination of the linear regression. In the literature, the a-value is the productivity. (M_c) is the minimum value where the earthquake distribution shows a linear character.

The recurrence relation of earthquakes follows the cumulative Gutenberg-Richter relationship (formula 6 is below):

$$\log N(M) = a - b M \qquad (6)$$

***Table 2.** Statistical parameters (a- and b-value, M_{min}-M_{max}) calculated for area seismic zones*

Area seismic zone	Mechanism	a-value	b-value	M_{min}	M_{max}
Zone 1	Strike slip	4.19	1.07	5.0	6.5
Zone 2	Strike slip	4.27	1.09	5.0	6.5
Zone 3	Strike slip	4.28	1.15	5.0	6.5
Zone 4	Strike slip	3.01	0.89	5.0	6.5
min: Minimum, max: Maximum					

The parameters for this relationship were established using geologic data on the historical occurrence of earthquakes and on regional tectonic movements. The b-value represents the relative proportion of the earthquakes that have different magnitudes. If the b-value is 1, then it represents a recurrence relationship that a magnitude 5 earthquake happens once a year and a magnitude 6 earthquake will occur in 10 years. The a-value is the intercept of the recurrence line at M equals zero. Higher a-values represent a higher overall level of seismicity. The a-value generally changes from one seismic source to another source, but the b-value is stable parameter for a seismic region. A cut-off magnitude of 5 was used as the lowest magnitude value for the definition of magnitude-frequency relationships of the proposed seismic model.

3.5. Selection of Attenuation Relationships

Another basic input to seismic hazard computations is an equation (or equations) that is referred to as an attenuation relationship, which predicts the expected ground motion at a site within a given distance from an earthquake of a known magnitude, usually deliberated as the moment magnitude. When the earthquake distributions have been determined for all the seismic sources, then, for a given magnitude, distance, and rupture mechanism, attenuation relationships are applied to evaluate the distribution of ground motion.

Strong ground motion is typically characterized by PGA or SA, or both. Attenuation equations tend to be regionally specific and may depend on site conditions. Assuming that a magnitude M earthquake occurs at a distance R (from site to event source), the PofE of ground motion level z could be calculated. In many parts of the world, numerous studies were accomplished using strong motion records. As a result, a log-normal distribution is generally consistent with the data, having the following mean value (formula 7 is below):

$$\text{In}(z) = c_1 + c_2 M_i + c_3 \text{ In } R_i + c_4 R_j \quad (7)$$

In this equation, Z is the ground motion variable, and c_1 through c_4 are empirically specified constants. $R_{i,j}$ and M_i are the distance and magnitude, respectively.

The earthquake ground motion attenuation relationships implemented in this study are those developed by the Next-Generation Attenuation (NGA) relationships of Abrahamson and Silva [35], Boore and Atkinson [36], Campbell and Bozorgnia [37], and Chiou and Youngs [38]. These relationships were derived empirically in accordance with the statistical analysis of ground motions recorded during past earthquakes from around the world. These relationships were developed under the Pacific Earthquake Engineering Research Center NGA project and represent the state-of-the-art in attenuation relationships using a large database of strong motion recordings of shallow crustal earthquakes. The validity of the attenuation relationships obtained by using hazard calculations was analyzed in many scientific project and papers in Turkey. Thus, no limitations in the use of these relationships for further studies exist. Some works include Seismic Hazard Harmonization in Europe (ESHM13, Woessner et al. [39]); Earthquake Model of the Middle East Region (Danciu et al. [40]; Danciu et al. [41]; Akkar et al. [42]; Global Earthquake Model; National Earthquake Research Program (UDAP-C-13-06); Ambraseys [43]; Sesetyan et al. [44]; and Demircioğlu et al. [45].

3.6. Logic Tree Approach Used for Hazard Model

Two types of uncertainty can be defined in earthquake hazard assessment studies; aleatory uncertainty and epistemic uncertainty [27]. Aleatory uncertainty is a result of the unpredictable nature of the physical process, while epistemic uncertainty is the output of the uncertainties and unknowns in our knowledge. In this research, aleatory uncertainty is presented by the standard deviation of the ground motion attenuation relationships, which is distributed log-normally; this corresponds to the increase in the median hazard. Epistemic uncertainty is presented by the integration of applicable ground motion attenuation relationships and seismic sources. It is achieved by using a logic tree approach (Figure 6).

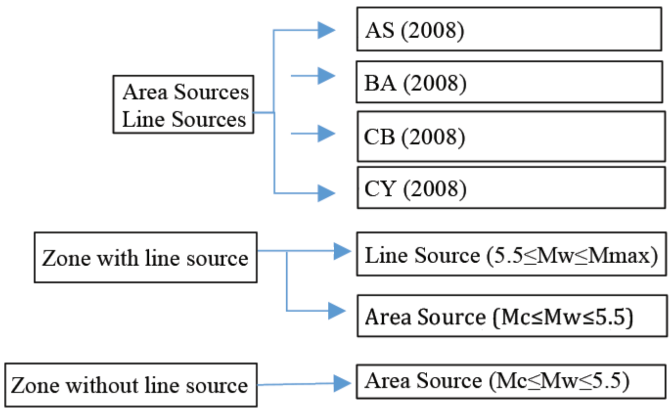

Figure 6. *Logic tree approach used for hazard model*

4. Findings and Discussion

The PSHA is computed by Ez-Frisk Manual software [46] (Risk Engineering, 2015) for a point with the coordinates 40.4160° N latitude and 49.9034° E longitude. This assessment includes the estimation of the severity of ground shaking on site soil conditions, B/C soil boundary condition Vs_{30}=760 m/s at a PofE of 2%, 10%, 29%, and 50% in 50 years [corresponding return periods (T_R), T_R=2,475 years, T_R=475 years, T_R=144 years, and T_R=72 years]. NGA relationship NGA-W1 is utilized to compute the resultant geometric mean (geo-mean) of 5% damped horizontal uniform hazard spectra (UHS) for a period range of 0.01 s-8 s.

On the basis of the adopted attenuation relationships, for PofEs of 2%, 10%, 30%, and 50% in 50 years, this study suggests PGA values in horizontal components not less than 0.694, 0.437, 0.274, and 0.200 g, respectively. A summary of PGA, Sa at 0.2 s, and Sa at 1.0 s values of the different estimated return periods are given for geometric mean and maximum rotated in Table 3. The maximum direction spectral ordinates are obtained by modifying Sa^{GM} with period-dependent factors proposed in Huang et al. [47]. These factors are also suggested in the 2009 edition of the National Earthquake Hazard Reduction Program [48], provisions (BSSC, 2009), and the ASCE/SEI 7-10 (ASCE, 2010) document. The resultant 5% damped horizontal UHS of T_R=2,475 years, T_R=475 years, T_R=144 years, and T_R=72 years are illustrated in Figure 7 (geo-mean) and Figure 8 (maxrRotated) for B/C soil boundary condition with shear velocity V_{S30}=760 m/s.

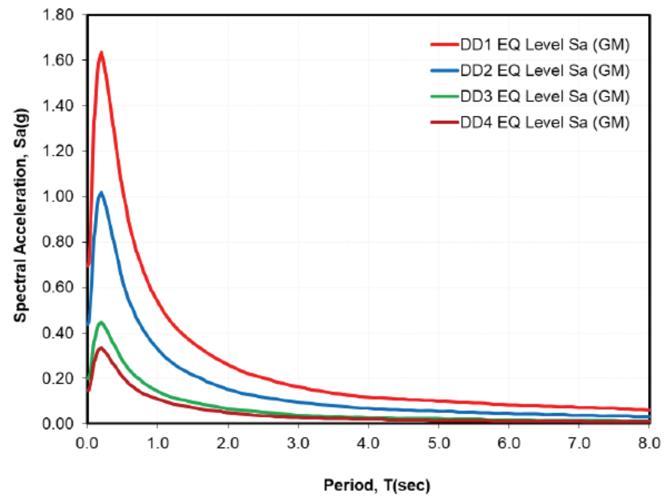

Figure 7. *Site-specific UHS for V_{S30}=760 m/s*

UHS: Uniform hazard spectra, EQ: Earthquake, GM: Geometric mean

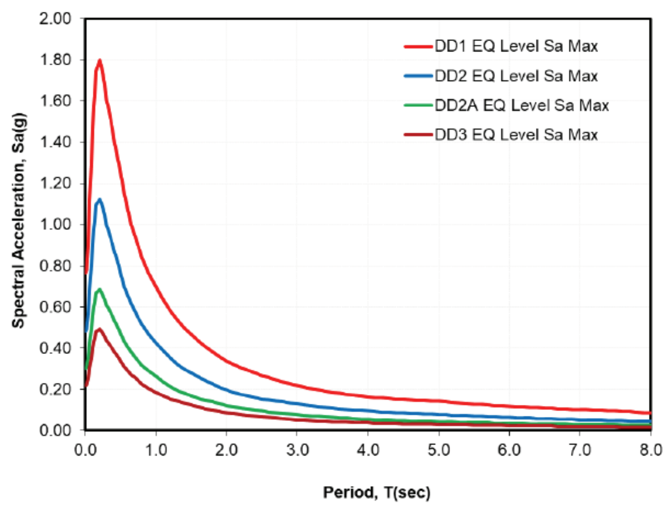

Figure 8. *Site-specific UHS for V_{S30}=760 m/s (max rotated).*

UHS: Uniform hazard spectra, EQ: Earthquake, Max: Maximum

Table 3. *Summary of PGA in vertical components, Sa (0.2) and Sa (1.0) values of different estimated return periods assuming soil shear velocity V_{S30}=760 m/s*

EQ level	Return periods (years)	Exc. Prob. in 50 years (%)	Max. PGA (g)		Sa (T=0.2 sec)		Sa (T=1.0 sec)	
			Geo-mean	Max-rot	Geo-mean	Max-rot	Geo-mean	Max-rot
E-1	**2475**	**2**	0.694	0.763	1.634	1.797	0.537	0.698
E-2	**475**	**10**	0.437	0.481	1.019	1.121	0.328	0.426
E-2A	**144**	**30**	0.274	0.301	0.623	0.685	0.204	0.265
E-3	**72**	**50**	0.200	0.219	0.448	0.492	0.142	0.184

PGA: Peak ground acceleration, EQ: Earthquake

The vertical spectrum was obtained from the product of the average of V/H ratio GMPEs and for PofEs of 2%, 10%, 30%, and 50% in 50 years. The V/H ratios suggested by Gülerce and Abrahamson [49] are utilized, and the site-specific vertical spectrum is obtained from the product of average of V/H ratio GMPEs. Site-specific vertical spectra for B/C boundary site conditions with shear velocity V_{S30}=760 m/s are illustrated in Figure 9 and Table 4.

Table 4. *Summary of PGA in vertical components, Sa (0.2), and Sa (1.0) values of different estimated return periods assuming soil shear velocity V_{S30}=760 m/s*

EQ level	Return periods (years)	Exc. Prob. in 50 years (%)	Max. PGA (g)	Sa (T=0.2 sec)	Sa (T=1.0 sec)
E-1	2475	2	0.504	0.908	0.319
E-2	475	10	0.318	0.566	0.195
E-2A	144	30	0.145	0.249	0.084
E-3	72	50	0.107	0.186	0.604

PGA: Peak ground acceleration, EQ: Earthquake

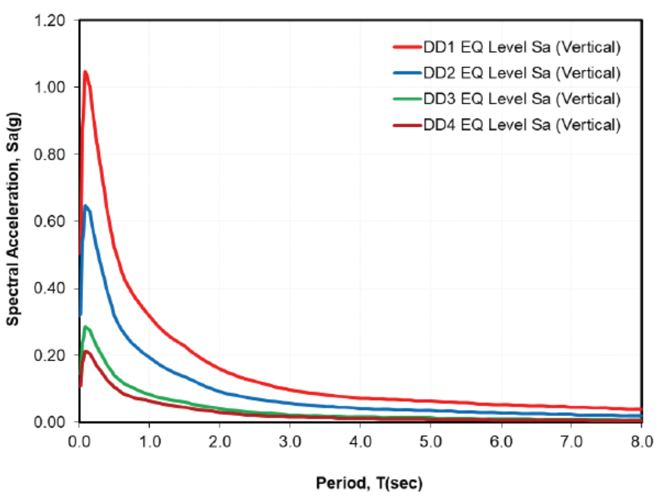

Figure 9. *Site-specific UHS for V_{S30}=760 m/s (vertical component)*

UHS: Uniform hazard spectra, EQ: Earthquake

Finally, to provide a better perspective to evaluate the results of this study, Table 5 shows a summary of PGA, Sa at 0.2 s, and Sa at 1.0 s values compared with the RHA seismic code [7] and the Turkey Building Earthquake Code [50].

5. Conclusion

This study aims to develop probabilistic seismic hazard assessments for the coastal area of Haydarpaşa Port site to clarify the seismic loading evaluation of marine ports around İstanbul. The calculation was performed for B/C boundary conditions and the findings are for the average of the two horizontal components of ground motion. The estimation of seismic hazard depends not only on the regional tectonics and the precise characterization of the faults within the area of interest, but also on the implemented analysis procedures and the variety of physical and empirical models, which are considered as the most suitable models for the required analysis.

In conclusion, with the aim of implementing the optimum empirical or physical models and calibrating the uncertainty in the findings accurately, this study used a set of alternative identification of the sources of seismic ground motion in addition to a multi-model simulation of seismic ground motion attenuation. This work presents a fair discussion of the foremost applicable assessments of literature in this field of interest. All works agree that the engineers who are involved in the long run in the design process are a key component. Engineers are expected to analyze the literature to make a precise decision as to whether the selected safety criteria are applicable to the relevant behavior objectives or not. This study aims to support practicing engineers in mastering seismic design codes. This training is considered an urgent need in implementing the standards and codes accurately for marine ports.

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Table 5. *Summary of PGA in vertical components, Sa (0.2), and Sa (1.0) values of different estimated return periods assuming soil shear velocity V_{S30}=760 m/s*

EQ level	Return periods (years)	Exc. Prob. in 50 years (%)	Max. PGA (g)			Sa (T=0.2 sec)			Sa (T=1.0 sec)		
			This study	RHA-2007	TBEC-2018	This study	RHA-2007	TBEC-2018	This Study	RHA-2007	TBEC-2018
E-1	2475	2	0.694	0.72	0.659	1.634	1.80	1.643	0.537	1.02	0.459
E-2	475	10	0.437	0.48	0.387	1.019	1.19	0.945	0.328	0.58	0.261
E-3	72	50	0.200	0.25	0.163	0.448	0.62	0.376	0.142	0.23	0.163

PGA: Peak ground acceleration, EQ: Earthquake, RHA: General Directorate for Construction of Railways, Harbors, and Airports, TBEC: Turkey Building Earthquake Code

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ARDL Bound Testing Approach for Turkish-Flagged Ships Inspected under the Paris Memorandum of Understanding

Selen Uygur[1], **Fırat Bolat**[2]

[1]Oceangoing Watchkeeping Officer, İstanbul, Turkey, İzmir, Turkey
[2]İstanbul Technical University Maritime Faculty, Department of Marine Engineering, İstanbul, Turkey

Abstract

The Paris Memorandum of Understanding (MoU) publishes a white, gray, and black list, presenting the full spectrum from quality flags to flags with poor performance that are considered high or very high risk every year. At this point, increasing the flag's performance can be achieved by eliminating the deficiencies and detentions in the ships. In this context, the aim of this study is to examine the performance of Turkish-flagged ships under the Paris MoU port state control (PSC) to determine the deficiencies of the ships and to make suggestions for measures that may be taken by the Republic of Turkey as a relevant flag state. Accordingly, the PSC data of Turkish-flagged ships between 2013 and 2020 in the EMSA THETIS have been analyzed. Comparison and descriptive distributions for the data of Turkish-flagged ships have been performed by creating cross tables of the distribution of ship type, inspection type, age of ships, detention ports, and detention decisions. An autoregressive distributed lag bound test has been carried out to understand whether the deficiencies and age of the ships can significantly affect the detention decision of ships at the port under the Paris MoU. Consequently, while deficiencies on the ships are found to significantly affect the decision of the detention of ships, the age of ships doesn't have a significant effect under the Paris MoU.

Keywords

Flag performance, Port state control, Paris memorandum of understanding

1. Introduction

Flag performance has become an important issue in maritime, especially after the signing of the regional memorandums of understanding. Ships belonging to states with low flag performance become targets of the regional Memorandum of Understanding (MoU) regimes wherein ships can wait at the port during the port state control (PSC) or after the control if they have any deficiencies. This waiting process causes delays in the workflow and, accordingly, money losses arising from port fees. This also causes the ship operator to lose money and reputation due to the ship's loss of the next load.

Increasing the flag performance is the responsibility of the relevant flag state as well as ship operators such as the crew, captain, marine company, and shipowner. Corres and Pallis [1] stated that the flag states are primarily responsible for the safety and environmental protection performance of their ships and that they fulfill these duties through international conventions and national law. According to Mansell [2], each flag state must take measures to ensure the safety of ships carrying its flag in terms of construction, equipment, and seaworthiness. International conventions require each ship to be inspected by an authorized auditor at regular intervals before and after the registration of the ship registry. However, inspections made by the flag states and international maritime authorities failed to eliminate the sub-standard ships in the sector, and the heavy maritime traffic and related accidents, especially since the 1960s, have threatened the safety of life and property at sea and marine environment [3]. In addition, after the 1970s, maritime regulations began to diverge from the ideal situation with debatable practices of some flag states [4].

Address for Correspondence: Fırat Bolat, İstanbul Technical University Maritime Faculty, Department of Marine Engineering, İstanbul, Turkey
E-mail: bolatf@itu.edu.tr
ORCID ID: orcid.org/0000-0001-9807-7089

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Despite the complex and comprehensive legal framework in the maritime sector, the implementation of these laws could be insufficient due to the international nature of the sector and could vary widely at the level of flag states [5]. This situation has pushed the port states, which were affected by the pollution that emerged after the marine accidents (Torrey Canyon 1968 and Amoco Cadiz 1979) involving ships carrying foreign flags, and those that did not have a connection with the relevant ship to seek new searches. Hence, the PSC has been developed to control the ships entering their own ports or coastal facilities. Inspections by PSC have been carried out to determine whether the ships meet the safety and pollution prevention requirements and whether they comply with the standards in relevant international conventions [6]. Under the PSC, a port state can take administrative measures such as keeping the ship at the port until corrective measures are taken or directing it to the nearest shipyard for repair. Since its emergence, PSC has played an important role in protecting the marine environment and in improving safety. Moreover, PSC has contributed to issues such as protecting international maritime standards, preventing pollution, ensuring property and life safety in the scope of international conventions such as SOLAS, MARPOL, STCW, LOADLINES, COLREG, TONNAGE 69, and ILO147. The Paris MoU, which is signed by 13 European countries in 1982, is the first regional PSC regime. After the Paris MoU, 8 other regional PSCs are developed, which include the Tokyo MoU, Indian Ocean MoU, Mediterranean MoU, Acuerdo de Viña del Mar, Caribbean MoU, Abuja MoU, Black Sea MoU and Riyadh MoU, and the US Coast Guard for United States region. These regional MoUs apply international rules and form a second line of defense against non-standard shipping [5]. Each PSC audit generates an inspection report, which includes detailed information on the deficiencies, including the flag, International Maritime Organization (IMO) ship number, ship type, construction year, and inspection date [7]. These reports are made into annual reports and published by each MoU regime. In this direction, the regional memorandums of understanding try to ensure that the ships that do not meet the standards will not be able to trade in any region of the world through cooperating and exchanging inspection data [2]. In this context, PSC regimes do not replace the unit that controls the inspections of the flag states on ships, but they are a body that inspects the compliance of ships with maritime conventions. A supportive practice to flag states for the inspections of the ships [8,9].

PSC detention rates of ships have been used for many years to measure the performance of flag states [2]. The issue of measuring the flag state performance was first initiated by the oldest PSC regime, Paris MoU, and was subsequently adopted by the Tokyo MoU [5]. These statistics are compared with the detentions in the entire PSC regime region, and flag states below a certain average can be identified and become targets for future inspections [2]. Since 1999, PSC regimes have been creating and publishing black, gray, and white lists by examining and processing the audit data they obtain every year, and by placing the flag states under these lists according to their performance [2,5]. Accordingly, the PSC's data is a powerful measure of the performance of a flag state. Through these PSC performances, most people who are associated with the maritime industry gain views on the value of flags. Theoretically, a high PSC inspection rate for a particular flag decreases the attractiveness of the flag as it degrades the performance of that flag and thus causes delays and loss of time and money [4].

The detailed reporting of the inspections within the scope of PSC, the inclusion of lots of information about the ship in the reports, and the processing and sharing of this information with other regional MoUs aim to reduce the non-standard practices in the global maritime system. The presence of deficiencies on the ship during these inspections causes the inspection to take longer, and the serious deficiencies cause the ship to be kept. These detention periods cause financial losses for the operator and loss of reputation for the flag state. Control and detention rates are considered indicators of the performance of a flag state, and low performance in an MoU regime can reach other MoUs due to information sharing between MoU regimes. In this way, low-performance flags become the primary control target of other MoU regimes. By operating the legal rights and responsibilities of the flag state arising from international conventions, seriously taking the mandatory inspections that are carried out at regular intervals prevent the ships from detention by the regional MoU regimes. Decreasing ship detention rates increases flag performance, prevents ship operators from losing time and money, and ensures that the relevant flag is off the radar of regional MoU regimes.

In this context, the aim of this study is to examine the performance of Turkish-flagged ships under the Paris MoU PSC to determine what the deficiencies of the ships are and to make suggestions for measures that may be taken into consideration by the Republic of Turkey as the relevant flag state. Comparison and descriptive distributions of data have been performed for Turkish-flagged ships under the Paris MoU by creating cross tables of distribution of ship type, inspection type, age of ships, detention ports, and detention decisions. An autoregressive distributed lag bound (ARDL) time-series analysis has been carried out to understand whether the average number of deficiencies that have been found on the ships and the average age of ships that have been inspected under the Paris MoU significantly affect the average number of detention decision of ships at port.

2. Literature Review

Life, property, and the environment are the most important issues in international transportation in the maritime world. Although the maritime industry is comparatively safe, it also includes a huge cost of accidents related to humans, the economy, and the environment. To measure these cases, the IMO, which is the prescriptive body in the maritime industry, has enhanced approximately 50 conventions that are as the legislative framework. Coastal states and flag state authorities take preventive actions in the light of the IMO conventions and national rules due to the high costs of accidents. However, inspections and controls of flag states on the vessels are not effective because of ships working in long distances, lack of experience, deployment of flags of convenient applications, fast growth in world navigation fleet, and lack of sources [1]. Therefore, PSC was additionally established for ensuring navigation safety to prevent maritime environment pollution and to correct the problems of flag state controls. PSC inspects foreign ships in national ports to verify the condition of the ship. In this context, the purpose of PSC is to contribute to flag state inspection results that were inadequate for inspecting compliance of the vessels to international standards, and to impose enforcement measures to vessels violating these standards. PSC inspections benefit the coastal state by providing safety of life, property, and environment while measuring the performance of the flag state of ships.

There are various studies in the literature about PSC inspection and its benefits that support the measurement of the performance of vessels. For example, Heij et al. [10] analyzed the effect of PSC inspections on the topic of safety to lower the accident victim risk by associating the inspection data with the accident victim. They also researched the probable safety achievements that can arise from luculently including the vessel's particular risk for future accidents to planning vessel inspection strategies.

Aydemir [11] analyzed the defects identified at the vessels under a ship inspection report program. In his study, 393 inspections between 2006 and 2014 for 16 maritime companies have been examined in the scope of 9 different MoUs and 40 different ports. The results of the study revealed that the percentage of deficiencies of the firms taken under control were quite close to each other. Deficiency items for these companies have been aligned as sections of safety management, petroleum, chemical, LPG and LNG, and the machinery and steering system.

Bayram [12] investigated the reasons for the detention of Turkish-flagged vessels as a result of PSC in the Paris, Mediterranean, and Black Sea Memorandums. In this context, all the deficiencies of the Turkish-flagged ships detained in 2005-2008 were determined, and the detected deficiencies were examined under 19 headings. In all three MoU inspections, it was determined that Turkish-flagged ships were weak in fire safety and precautions, lifesaving appliances, and MARPOL, and the detention reasons were more intense on these issues.

According to the Paris MoU inspections report in 2019 [13], 17908 inspections actualized in the coast of the Paris MoU member and 9320 deficiencies, 526 detentions, and 27 bannings were found. Forty-one flag countries including the Turkish flag have been in the white list, while 16 and 13 flag countries have been in the gray and black list, respectively. The top five categories of deficiencies consist of the safety of fire (13%); safety of navigation (11%); lifesaving appliances (8%); labor conditions, welfare and social security protection, medical care, health protection (8%); and emergency systems (7%). In accordance with inspections in 2019 specifically for Turkish-flagged ships, 252 number of inspections have been carried out in which 159 of them were with deficiencies, 4 of them included detention, and 30 of them involved detainable deficiencies. As a result, 63.1% of inspections were with deficiencies and 1.6% of them comprised detention.

Fan et al. [4] established a statistical analysis for modeling the dynamic relationships between the PSC inspection rate and flag-out decision of the vessel operator. They made a binary choice logit model, which suppose maximization efficacy on the decision of the operator's flagging out, to understand the effect of PSC inspection on the flag-out decision. Accordingly, the main attributes for flagging out were the ship type, ship age, operator's nationality, and the determinants of the operator's characteristics, such as the GDP per capita and rate of income tax. In addition, if a vessel has a ship classification services from International Association of Classification Societies members, the ship is then less probably to flag out. The essential attributes for the rate of PSC inspection included the vessel tonnage, type, age, and operator's characteristics. Consequently, if a vessel flies a flag of convenience, it is more likely to be inspected.

Piniella et al. [14] made a comparative study for the ships detained in the scope of Viña del Mar, Tokyo, and Paris regional PSC. They found that the regional agreements on the PSC of Paris and Tokyo are in major cooperation with common directives and trainings of PSC inspectors in more internationally uniform ways.

Emecen Kara et al. [15] carried out a similarity analysis of PSC regimes on the strength of the flag state's performance. Similarities of the PSC regimes have been assessed by the hierarchical clustering method that utilized the risk levels similarity matrices of flag states, the deficiency and rates of detention similarity matrices, and the mixed similarity matrix.

Chung et al. [16] applied data mining for the time-wise assessment of the PSC inspection data in Taiwan's important ports to provide possible substantial data for PSC vessel inspections. This model determined various beneficial association rules through PSC deficiencies in the sense of particular vessel properties, such as vessel societies, flags, and types via the apriori algorithm. According to the analysis, there is a significant relationship between the watertight and weathertight conditions and fire safety items. The comparison analysis of vessel societies and vessel types reveals that the association rules for the particular vessel types have better impact than those for individual vessel societies.

There are some studies suggesting that the ship's age is an important factor for the detention of ships or deficiencies finding onboard. For instance, Cariou and Wolff [17] found that a ship's age, type, and flag of registry are significant predictors. They used quantile regression analysis with a sample of 249,140 initial inspections. These inspections were carried out between January 2000 and December 2011 by 19 participating maritime administrations of the Tokyo MoU. Graziano et al. [18] made an ordinary least square regression model for determining that the differences in detecting at least one deficiency or detaining a vessel are significant among the member states. For that purpose, they used 32,206 PSC inspections that were carried out by the European Union and European Free Trade Association Member States within the Paris MoU region from 1 January 2014 to 31 December 2015. According to their results, there is a significant difference in some member states that the ship with at least one deficiency or detention is 40 percent less likely to be inspected than those with zero deficiency or detention. They also discovered that age is positively related to the deficiencies or detention. However, there is difference in the effect of the coefficient between the age levels. With the reference age, which is less than 5 years old, the probability of having a vessel detained increases by 4.7 percentage points when the vessel is more than 30 years old and by 2.1 percentage points for the number of deficiencies. In addition, according to their results, there are correlations between the role of the inspectors and PSC outcomes. Yılmaz and Ece [19] examined the inspection results of the Turkish-flagged ships inspected under the Paris MoU between 2011 and 2016. In this study, it has been aimed to examine the relationships between the types of inspected ships, the season of the inspection, the type of inspection performed, and the ages of the ships under inspection with the chi-square test (χ^2) method. According to the findings of the research, while the rate of detention was at the level of 3 percent in the comprehensive inspections carried out in the period between 2011 and 2016 under the Paris MoU inspection, it was observed that the average for Turkish-flagged ships was 4.7 percent. In conclusion, there was a statistically significant relationship between the number of deficiencies, age of ships, and the audit result. The difference of this study from Yılmaz and Ece's [19] study is the examination of the effect of deficiencies and age of ships on the detention of ships via an ARDL test. Besides that, this study presents comparatively descriptive information about the Turkish-flagged vessels inspected under the Paris MoU and shows the performance of Turkish-flagged vessels. On the other hand, the Paris MoU has forced a new regime of inspections (NIR) in 2011. According to the NIR, the "ship risk profile" has been taken instead of the "ship target factor" in the system and ships have been classified in different risk groups such as low-risk ships and high-risk ships. In this context, Piniella and Rodriguez-Diaz [20] made a statistical analysis to find which factors are the most significant for the Paris MoU officers in determining which ships to inspect in the NIR. The variables used in their study were the flag state, classification society, type of vessel, age of the ship, and ship risk profile. According to their results, while the flag state, type of vessel, and ship risk profile were important factors in the NIR, the classification society and the age of the ship were not important variables on the degree of risk that the ship presents. As a result, this study is one of the papers that suggested that the ship's age does not have a significant effect on detention.

Similarly, there are other studies with unexpected results for the effect of the ship's age and contrary to the industrial perception. For instance, Knapp and Franses [21] showed that the basic ship profiles given by age, size, flag, class, and ownership did not vary significantly across the regimes with respect to the probability of detention. The deficiencies have the most differences across the regimes for detention and port states. They made binary logistic regression using the data of 183,819 port state inspections from various PSC regimes for the interval of 1999 to 2004. In accordance with their results, only the differences in port states and the treatment of deficiencies significantly affect the probability of detention while flag, owner, age, class, or size as perceived by the regulators and industry do not have significant effect on the detention of ships. Li et al. [22] provided an improved quantitative safety index for each international sea-going vessel based on their condition information and safety records. The safety index involves static and dynamic information of merchant vessels around the world and produce a risk score via binary logistic regression. The safety index can be used by port authorities to determine whether an onboard inspection is needed for vessels calling at their ports to prevent oil pollution and accidents within their territorial waters. For that purpose, they initially determine the parameters constituting the safety risk. As a result, they discovered that increasing the vessel age is related to increasing the level of vessel safety. Although the relationship has a fractional coefficient (0.001) in their result, this may be a reflection of the fact that the survival vessels are proved to be quality or well-maintained ones.

On the other hand, there are many studies stating that the ship's profile determines the scope, frequency, and priority of inspections instead of the outcomes of inspections [23-25].

Compared with existing research, our study has two distinctive features. The first feature is to demonstrate that unlike the industry's point of view and the conclusion of traditional studies, the age of the ship does not have a significant effect on the detention of the Turkish-flagged ship within the scope of the Paris MoU inspections and that the ship's deficiencies have a significant effect on the detention of the ship. The second feature is the use of time-series analysis based on ARDL method in determining whether the parameters of ship's age and deficiencies affect the detention of Turkish-flagged vessels.

3. Methodology

3.1. Auto Regressive Distributed Lag Bound (ARDL)

A linear combination of non-stationary series can be considered stationary. Such variables are called cointegrated variables. The linear composition is generally related to economic theory. According to the economic interpretation of cointegration, if two or more series are related to each other in such a way as to form an equation of equilibrium that extends over a long period, they move closely with each other over time and the difference between them is stable even if the series contain a stochastic trend (not stationary). In this case, the concept of cointegration means that the economic system converges in time and a long-term equilibrium relationship exists [26].

Although the concept of cointegration has been introduced in the literature by Engle and Granger [27], there are many cointegration tests based on the application of unit root tests to residues that are calculated from the cointegration model. In this study, the ARDL boundary test method was used to investigate the existence of cointegration relationships. In the selection of the ARDL bounds test, it was taken into consideration that the test could detect the existence of a cointegration relationship without taking into account the stationary characteristics of the variables. To put it more clearly, the ARDL boundary test method becomes more useful than the Engle and Granger [27] and Johansen [28] tests because it allows the examination of a cointegration relationship between the differentially integrated series. Since the variables in the research model are integrated to different degrees, ARDL bounds test approach was adopted in the study.

ARDL test is one of the cointegration tests that enables the examination of the relationships between non-stationary variables in econometrics. The ARDL limit test method has some advantages over other cointegration tests, which include the following: It gives the coefficient for the long-term relationships. It can be applied to variables that are equally non-stationary and integrated of different order at most I [1]. Trend and constant specifications are quite wide. It is based on error corrections and works with the condition of balancing long-term deviations. It is not enough to only have the long-term equilibrium. It also requires balancing the deviations from the long term in addition to the equilibrium by the error correction term [26].

The ARDL limit test approach consists of two stages. In the first stage, the existence of long-term relationships between variables is tested. In the second stage, the short- and long-term coefficients of the series that are determined to be cointegrated in the first stage are calculated. For better understanding, the following equation is estimated to test the long-term relationship in the boundary test approach for a bivariate research model [29]. Formula 1 is below:

$$\Delta Y_t = \beta_0 + \beta_1 Y_{t-1} + \beta_2 X_{t-1} + \sum_{i=1}^{p} \delta_i \Delta Y_{t-1} + \sum_{i=0}^{q} \lambda_i \Delta X_{t-i} + \mu_t \quad (1)$$

Symbols in Equation (1) are expressed as follows;

p=optimal lags in the dependent variable

q=optimal lag number in the independent variable

β0, β1 β2, δi, and ⋋i: coefficients

Δ=difference of the variable.

The null hypothesis for the cointegration relationship between variables is as in Equation (2) below;

$$H\_0: β\_1 = β\_2 = 0 \quad (2)$$

If the calculated test statistic is less than the specified lower critical limit, the null hypothesis, which states that there is no cointegration relationship, cannot be rejected. If the test statistic is greater than the specified upper critical limit, the null hypothesis is rejected and it is decided that the cointegration has been established. If the test statistic is between the lower and upper limit values, no decision can be made regarding the cointegration [29].

After determining that there is cointegration between the series, the ARDL (p, q) model is estimated as shown in Equation (3) below [29].

$$Y_t = \beta_0 + \sum_{i=1}^{p} \delta_i Y_{t-i} + \sum_{i=1}^{p} \lambda_i X_{t-i} + \mu_t \quad (3)$$

In the ARDL (p, q) model, the long-term coefficients for the independent variable are estimated as in Equation (4) below.

$$\frac{\lambda_0 + \lambda_p + \cdots . \lambda_p}{1 - \delta_1 + \delta_2 + \cdots \delta_q} \quad (4)$$

After estimating the long-term coefficients, the short-term coefficients are obtained by establishing an error correction model (Equation 5 as below).

$$\Delta Y_t = \beta_0 + \beta_1 EC_{t-1} + \sum_{i=1}^{p} \delta_i \Delta Y_{t-i} + \sum_{i=1}^{q} \lambda_i \Delta X_{t-i} + \mu_t \quad (5)$$

The "EC" in the Equation (5) refers to the error correction term. To test the existence of the causality relationship from the independent variables to the dependent variable, the error correction term must be meaningful and must be between 0 and -2.

To determine the optimal lag lengths for the ARDL (p, q) model, the Aike information criterion has been taken into account. Many different lag length specifications can be created and compared according to the Aike information criterion, but recent econometric package programs determine the optimal lag length according to the comparison criteria, saving the researcher from this effort.

3.2. Application of ARDL Test for Turkish-Flagged Ships in the Scope of Paris MoU

In this study, the data frequency distribution of ship type, inspection type, construction year of the ship, detention port, and detention decisions are shown by creating cross tables on the data. This gives the comparison and descriptive information for the data on the Turkish-flagged ships that have been inspected in the scope of the Paris MoU. Besides that, the ARDL test is carried out to determine whether the average number of deficiencies that have been found on the ships and the average age of ships that have been inspected under the Paris MoU significantly affect the average number of detention decisions of ships at the port. Cross tables are created via the SPSS program and the ARDL test is performed via the E-views program.

Cross tables of data are then presented and the summary statistics of the variables in the research model (ARDL test) is given. The variable time course charts are examined to determine the trend and structural break properties of the variables. The seasonality of the variables is then examined using the F and Kruskal-Wallis H tests, which reveal no observed seasonal effects.

The variables in the time-series regression models have conditions for being stationary. A pseudo-regression model is established between two or more non-stationary variables. The predicted models generally give good results in the case of pseudo-regression. However, despite the high R^2 and statistically significant models in pseudo-regression, the predicted parameters are generally insignificant because the non-stationary variables randomly move in the same direction. Pseudo-regression can occur between two completely unrelated non-stationary variables and in interrelated macroeconomic and financial series [30].

Augmented Dickey-Fuller (ADF) unit root tests are applied to determine the stationary states of the variables. The ADF unit root test determines whether the series is stationary or not. This method is an improvement of the Dickey-Fuller (DF) unit root test by taking into account the autocorrelation problem in contrast with the DF unit root test. The ADF proposes the solution of three equations [Equations (6, 7, 8)] to answer whether a Yt series is stationary at the level with the unit root test [31].

For $Y_t \sim I(0)$;

Equation without constant term and trendless:

$$\Delta Y_t = \beta_1 Y_{t-1} + \sum_{i=1}^{p} \sigma_i \Delta Y_{t-i} \quad (6)$$

Equation with constant terms:

$$\Delta Y_t = \beta_0 + \beta_1 Y_{t-1} + \sum_{i=1}^{p} \sigma_i \Delta Y_{t-i} \quad (7)$$

Equation with constant and trend:

$$\Delta Y_t = \beta_0 + \beta_1 Y_{t-1} + \beta_2 \, Trend + \sum_{i=1}^{p} \sigma_i \Delta Y_{t-i} \quad (8)$$

The ADF test requires the estimation of one, more, or all of the regression specifications in equations (6), (7), and (8) with the least square values. Two conditions must be met for the stationarity of the series: (1) The coefficient of β1 should be negatively signed. (2) The coefficient should be statistically significant [31].

The null hypothesis and the alternative hypothesis for the ADF test are as follows;

H0: There is a unit root in the series.

H1: There is no unit root in the series.

Throughout the specifications, the deterministic process is the constant and the trend. Unnecessarily adding a constant or trend variable will reduce the strength of the test, which may end up concluding that the stationary series is not stationary. The dependent variable delays in the equation are intended to overcome the possible autocorrelation problem in the error terms. A decision is made if the test results indicate that all three specifications point to the unit root in the same place or if the unit root is absent [31].

In the case where the variables to be used in the regression models are non-stationary, a frequently used method is to make the variables stationary by taking their differences. However, Granger and Newbold explained that it is not appropriate to use non-stationary variables in this way because it eliminates the information about the long-term relationship [32]. For this reason, the ARDL test is performed in this study.

3.2.1. Data Collection

The data used for this study are obtained from EMSA THETIS, which is the Paris MoU database [33]. In this context, the data collected include the detention port, detention date, ship age, number of deficiencies, and type of ship belong to Turkish-flagged ships that have been inspected between 2013 and 2020 in the scope of the Paris MoU. Two thousand seven hundred-2779 sample observations from 2013 to 2020 are acquired from the EMSA THETIS. These data are then transformed into monthly data sets to obtain the time series by averaging the information of related variables. The data are categorized according to the average age of the ships that have been inspected every month, average number of deficiencies that have been found in the ships every month, and the average number of detentions for each month under the Paris MoU. Hence, longitudinal data is created for the time-series analysis. Longitudinal data are those data where the same variable or variables have been measured at different time points. Based on the analysis of longitudinal data, the development of individuals over time can be observed by comparing them within themselves and with each other. To determine if the examined variables are affected by different variables to reach the result of interest in the analysis of longitudinal data, the data can also be examined with multi-level analysis methods [34]. For the ARDL test, the data of all variables are collected at a monthly frequency between the 2nd month of 2013 and the 12th of 2020. A time-series data set containing 95 observations is then created. Frequency data distributions of the variables are also shown as cross tables.

3.2.2. Analyses and Findings

Step 1 - Cross tables for Performance Analysis

Cross tables are created to see the frequency distribution and descriptive features of the detained Turkish-flagged ships under the Paris MoU according to other variables. While these tables provide us the opportunity to interpret the data distribution by comparing the variables, the distribution table including the ship's age provides preliminary information during the hypothesis phase for ARDL test.

In this context, the distribution of the detention situation of ships according to the ship type between 2013 and 2020 years is shown in Table 1. In general, it is seen that the general cargo (1331) is the most inspected Turkish-flagged ship type under the Paris MoU between 2013 and 2020. However, commercial yachts (31.8%) have the highest detention rate among the ship types.

In Table 2, the distribution of detention situations of ships according to the type of inspection is presented. It is seen that ships are less likely to be detained during initial inspection in the scope of the Paris MoU. Vessels are most often detained during a more detailed inspection. However, only approximately 4.4% of the inspected ships are detained at the same time in total.

Data distribution of detention situations of ships according to the ship's age is given in Table 3. According to the data distributions, it is seen that more detained vessels at the port have ages of 30 years and older and the fewer detained vessels have ages of 10 year and below. This distribution shows the possibility that there may be a positive relationship between the ship's age and the detention of the ship. Therefore, the ARDL test is applied to prove whether the Turkish-flagged ship's age has a significant effect on the Turkish-flagged ship detention under the Paris MoU.

The distribution of detention situations of ships according to country in which the ships have been detained is shown in Table 4. It is seen that the countries with the most number of decisions of detention for ships include Canada, Slovenia, Poland, Germany, Belgium, and Italy.

Step 2 - ARDL

Within the scope of the research, an econometric model is established to examine whether the average number of deficiencies that have been found on the ships under the Paris MoU and the average age of ships that have been inspected under the Paris MoU significantly affect the average number of detention decisions of ships at port using Equation 9.

$$T_t = \alpha_t + \beta_1 Y_t + \beta_2 E_t + \varepsilon_t \qquad (9)$$

In Equation (9), α is the constant term, ε is the error term, and t subscript indicates the time dimension. β_1 and β_2 express the effect of age and deficiency variables on the detention variables, respectively. The definitions of the variables in the equation are summarized in Table 5.

The descriptive statistics of the variables used in the ARDL test are shown in Table 6. The average number of detentions of ships (T) per month between 2013 and 2020 reaches a maximum of 0.160 and has a minimum of 0.000. The average

Table 1. *Frequency distribution of detention situation of ships according to ship type*

	2013		2014		2015		2016		2017	
Type of ships	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**
General cargo	10 (4.3%)	223 (95.7%)	13 (5.3%)	232 (94.7%)	16 (8%)	183 (92%)	13 (6.9%)	175 (93.1%)	7 (5.2%)	128 (94.8%)
Container	2 (5.3%)	36 (94.7%)	3 (7.9%)	35 (92.1%)	0 (0.0%)	27 (100%)	1 (2.9%)	33 (97.1%)	0 (0.0%)	32 (100%)
Bulk carrier	1 (1.7%)	57 (98.3%)	3 (5.6%)	51 (94.4%)	3 (5.4%)	53 (94.6%)	0 (0.0%)	49 (100%)	2 (5.3%)	36 (94.7%)
Ro-Ro cargo	0 (0.0%)	16 (100%)	0 (0.0%)	11 (100%)	0 (0.0%)	14 (100%)	0 (0.0%)	20 (100%)	0 (0.0%)	21 (100%)
Commercial yacht	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	2 (22.2%)	7 (77.8%)	4 (36.4%)	7 (63.6%)
Chemical tanker	1 (1.7%)	59 (98.3%)	0 (0.0%)	48 (100%)	5 (11.1%)	40 (88.9%)	2 (3.4%)	57 (96.6%)	1 (2.3%)	43 (97.7%)
Passenger ship	0 (0.0%)	24 (100%)	4 (10.5%)	34 (89.5%)	0 (0.0%)	33 (100%)	1 (3.0%)	32 (97.0%)	0 (0.0%)	27 (100%)
Tug	0 (0.0%)	1 (100%)	0 (0.0%)	5 (100%)	0 (0.0%)	3 (100%)	0 (0.0%)	1 (100%)	0 (0.0%)	3 (100%)
Oil tanker	0 (0.0%)	14 (100%)	0 (0.0%)	7 (100%)	0 (0.0%)	9 (100%)	2 (16.7%)	10 (83.3%)	0 (0.0%)	10 (100%)
High speed passenger craft	0 (0.0%)	1 (100%)	0 (0.0%)	1 (100%)	0 (0.0%)	2 (100%)	0 (0.0%)	2 (100%)	0 (0.0%)	3 (100%)
Gas carrier	0 (0.0%)	3 (100%)	0 (0.0%)	3 (100%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	6 (100%)	0 (0.0%)	3 (100%)
Combination carrier	0 (0.0%)	0 (0.0%)	0 (0.0%)	2 (100%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (100%)	0 (0.0%)	0 (0.0%)
Offshore supply	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	2 (100%)	0 (0.0%)	0 (0.0%)
Other special activities	0 (0.0%)	0 (0.0%)	0 (0.0%)	8 (100%)	0 (0.0%)	3 (100%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Total	14 (3.1%)	434 (96.9%)	23 (5.1%)	431 (94.9%)	24 (6.1%)	367 (93.9%)	21 (5.0%)	395 (95.0%)	14 (4.3%)	313 (95.7%)

	2018		2019		2020		Total	
Type of ships	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**
General cargo	2 (1.4%)	140 (98.6%)	2 (1.85%)	108 (98.2%)	0 (0.0%)	79 (100%)	63 (4.73%)	1.268 (95.27%)
Container	0 (0.0%)	15 (100%)	0 (0.0%)	10 (100%)	0 (0.0%)	17 (100%)	6 (3.3%)	205 (96.7%)
Bulk carrier	1 (2.9%)	34 (97.1%)	0 (0.0%)	26 (100%)	0 (0.0%)	18 (100%)	10 (3.4%)	324 (96.6%)
Ro-Ro cargo	0 (0.0%)	22 (100%)	1 (4%)	24 (96%)	1 (4.35%)	22 (95.6%)	2 (0.0%)	150 (100%)
Commercial yacht	1 (50.0%)	1 (50.0%)	0 (0.0%)	0 (100%)	0 (0.0%)	0 (0.0%)	7 (31.8%)	15 (68.2%)
Chemical tanker	1 (2.2%)	45 (97.8%)	1 (3.22%)	31 (100%)	0 (0.0%)	22 (100%)	11 (3.3%)	345 (96.7%)
Passenger ship	1 (3.8%)	25 (96.2%)	0 (0.0%)	26 (100%)	0 (0.0%)	3 (100%)	6 (3.3%)	204 (96.7%)

***Table 1.** Frequency distribution of detention situation of ships according to ship type (Continued)*

	2018		2019		2020		Total	
Type of ships	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**
Tug	0 (0.0%)	6 (100%)	0 (0.0%)	3 (100%)	0 (0.0%)	1 (100%)	0 (0.0%)	23 (100%)
Oil tanker	0 (0.0%)	12 (100%)	0 (0.0%)	9 (100%)	0 (0.0%)	11 (100%)	2 (3.1%)	82 (96.9%)
High speed passenger craft	1 (14.3%)	6 (85.7%)	0 (0.0%)	5 (100%)	0 (0.0%)	0 (0.0%)	1 (6.3%)	20 (93.8%)
Gas carrier	0 (0.0%)	1 (100%)	0 (0.0%)	3 (100%)	0 (0.0%)	1 (100%)	0 (0.0%)	20 (100%)
Combination carrier	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (100%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	4 (100%)
Offshore supply	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (100%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	3 (100%)
Other special activities	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (100%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	5 (100%)
Total	7 (2.2%)	307 (97.8%)	4 (1.62%)	247 (99.3%)	1 (0.57%)	174 (99.4%)	108 (4.4%)	2.670 (95.6%)

***Table 2.** Frequency distribution of detention situations of ships according to type of inspection*

	2013		2014		2015		2016		2017	
Type of inspection	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**
Initial inspection	0 (0.0%)	144 (100%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
More detailed inspection	13 (5.3%)	231 (94.7%)	17 (4.4%)	367 (95.6%)	22 (6.7%)	304 (93.3%)	17 (5.0%)	325 (%95.0)	12 (4.7%)	244 (95.3%)
Expanded inspection	1 (1.7%)	59 (98.3%)	6 (8.6%)	64 (91.4%)	2 (3.1%)	63 (96.9%)	4 (5.4%)	70 (94.6%)	2 (2.8%)	69 (97.2%)
Total	14 (3.1%)	434 (96.9%)	23 (5.1%)	431 (94.9%)	24 (6.1%)	367 (93.9%)	21 (5.0%)	395 (95.0%)	14 (4.3%)	313 (95.7%)

	2018		2019		2020		Total	
Type of inspection	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**
Initial inspection	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	144 (100%)
More detailed inspection	7 (2.8%)	243 (97.2%)	4 (2.09%)	187 (97.91%)	1 (0.67%)	148 (99.3%)	93 (4.9%)	2049 (95.1%)
Expanded inspection	0 (0.0%)	64 (100%)	0 (0.0%)	61 (100%)	0 (0.0%)	27 (100%)	15 (3.7%)	497 (96.3%)
Total	7 (2.2%)	307 (97.8%)	4 (2.63%)	248 (97.3%)	1 (0.56%)	175 (99.4%)	108 (4.4%)	2.670 (95.6%)

Table 3. *Frequency distribution of detention situations of ships according to ship's age*

Age of ships	2013 Detained ships	2013 Not detained ships	2014 Detained ships	2014 Not detained ships	2015 Detained ships	2015 Not detained ships	2016 Detained ships	2016 Not detained ships	2017 Detained ships	2017 Not detained ships
10 year and below	2 (1.1%)	185 (98.9%)	1 (0.7%)	148 (99.3%)	4 (3.1%)	125 (96.9%)	4 (3.6%)	107 (96.4%)	3 (3.3%)	89 (96.7%)
11-20 year	4 (5.8%)	65 (94.2%)	7 (7.2%)	90 (92.8%)	6 (6.7%)	83 (93.3%)	7 (5.9%)	111 (94.1%)	5 (5.2%)	91 (94.8%)
21-30 year	4 (4.0%)	95 (96.0%)	4 (3.8%)	101 (96.2%)	6 (6.3%)	89 (93.7%)	3 (3.0%)	97 (97.0%)	2 (2.5%)	77 (97.5%)
30 year and older	4 (4.3%)	89 (95.7%)	11 (10.7%)	92 (89.3%)	8 (10.3%)	70 (89.7%)	7 (8.0%)	80 (92.0%)	4 (6.7%)	56 (93.3%)
Total	14 (3.1%)	434 (96.9%)	23 (5.1%)	431 (94.9%)	24 (6.1%)	367 (93.9%)	21 (5.0%)	395 (95.0%)	14 (4.3%)	313 (95.7%)

Age of ships	2018 Detained ships	2018 Not detained ships	2019 Detained ships	2019 Not detained ships	2020 Detained ships	2020 Not detained ships	Total Detained ships	Total Not detained ships
10 year and below	3 (3.8%)	76 (96.2%)	1 (2.0%)	49 (98.0%)	0 (0.0%)	17 (100%)	18 (2.3%)	796 (97.7%)
11-20 year	2 (2.0%)	100 (98.0%)	1 (1.2%)	82 (98.8%)	1 (1.25%)	79 (98.7%)	33 (5.4%)	701 (94.6%)
21-30 year	2 (2.4%)	81 (97.6%)	2 (2.7%)	72 (97.3%)	0 (0.0%)	47 (100%)	23 (3.7%)	659 (96.3%)
30 year and older	0 (0.0%)	50 (100%)	0 (0.0%)	45 (100%)	0 (0.0%)	32 (100%)	34 (7.2%)	514 (92.8%)
Total	7 (2.2%)	307 (97.8%)	4 (1.58%)	248 (98.4%)	1 (0.57%)	175 (99.4%)	108 (4.4%)	2.670 (95.6%)

Table 4. *Frequency distribution of detention situations of ships according to the country in which the ships have been detained*

Country	2013 Detained ships	2013 Not detained ships	2014 Detained ships	2014 Not detained ships	2015 Detained ships	2015 Not detained ships	2016 Detained ships	2016 Not detained ships	2017 Detained ships	2017 Not detained ships
Belgium	1	9	0	6	1	9	0	5	0	4
Bulgaria	1	54	1	54	0	37	0	50	0	31
Canada	1	5	1	4	1	4	0	3	0	3
Croatia	0	18	0	20	1	14	1	14	1	12
Cyprus	0	1	0	2	0	0	0	0	0	1
Denmark	0	1	0	1	0	2	0	1	0	0
France	0	19	0	25	0	15	0	16	0	15
Germany	1	2	0	6	1	7	0	5	1	2
Greece	1	64	7	93	5	86	3	84	5	82
Ireland	0	1	0	1	0	1	1	1	0	2
Italy	4	64	9	42	4	56	3	63	4	51
Latvia	0	1	0	3	0	2	0	0	0	2
Lithuania	0	2	0	3	0	1	0	1	0	0
Malta	0	2	0	1	1	2	0	1	0	1
Netherlands	0	10	0	6	0	7	0	6	0	4
Norway	0	1	0	0	0	1	0	1	0	1

Table 4. *Frequency distribution of detention situations of ships according to the country in which the ships have been detained*

	2013		2014		2015		2016		2017	
Country	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**
Poland	0	1	0	2	1	2	0	2	0	1
Portugal	0	9	0	11	0	11	1	19	0	11
Romania	1	88	2	86	3	58	9	55	2	38
Russian	0	21	0	15	2	12	0	27	0	10
Slovenia	2	7	0	8	1	4	0	0	0	6
Spain	2	45	2	36	1	32	2	32	1	30
Sweden	0	0	0	0	0	0	0	0	0	1
United Kingdom	0	9	1	5	2	4	1	10	0	5
Finland	0	0	0	1	0	0	0	4	0	0
Total	14	434	23	431	24	367	21	400	14	313

	2018		2019		2020		Total	
Country	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**	**Detained ships**	**Not detained ships**
Belgium	1	7	0	2	0	1	3	43
Bulgaria	0	23	0	20	0	14	2	283
Canada	0	2	0	2	0	1	3	24
Croatia	0	13	0	11	0	6	3	108
Cyprus	0	1	0	0	0	0	0	5
Denmark	0	0	0	0	0	2	0	7
France	1	7	0	14	0	12	1	123
Germany	0	4	0	1	0	1	3	28
Greece	3	73	2	68	0	30	26	580
Ireland	1	2	0	1	0	0	2	9
Italy	0	56	1	36	1	31	26	399
Latvia	0	0	0	0	0	1	0	9
Lithuania	0	1	0	0	0	1	0	9
Malta	0	0	0	2	0	1	1	10
Netherlands	0	6	0	4	0	2	0	45
Norway	0	0	0	1	0	0	0	5
Poland	0	4	0	2	0	1	1	15
Portugal	0	13	0	6	0	3	1	73
Romania	1	41	0	30	0	32	18	428
Russian	0	14	0	16	0	11	2	126
Slovenia	0	3	0	3	0	1	3	37
Spain	0	30	1	21	0	17	9	243
Sweden	0	1	0	1	0	0	0	3
United Kingdom	0	6	0	7	0	5	4	51
Finland	0	0	0	0	0	0	0	7
Total	7	307	4	248	1	173	108	2670

ship age (Y) variable has a maximum of 28 and a minimum of 11. The average number of deficiency (E) variable has a maximum of 4,714 and a minimum of 0.000. While T and Y variables do not fit the normal distribution according to the test statistics (Sig.<0.10), the E variable fits the normal distribution (Sig.>0.10). On the other hand, when the skewness coefficients of the variables are examined, it can be said that there is no significant skewness for all variables (|S|<1) [35,36].

The time course charts of the variables used in the study are presented in Figure 1, which reveals that all variables are time series that do not have a clear trend and do not show distinct structural break features. On the other hand, it can be said that the seasonal increases and decreases in the variables cause suspicion of seasonal effects. For this reason, seasonality tests are performed.

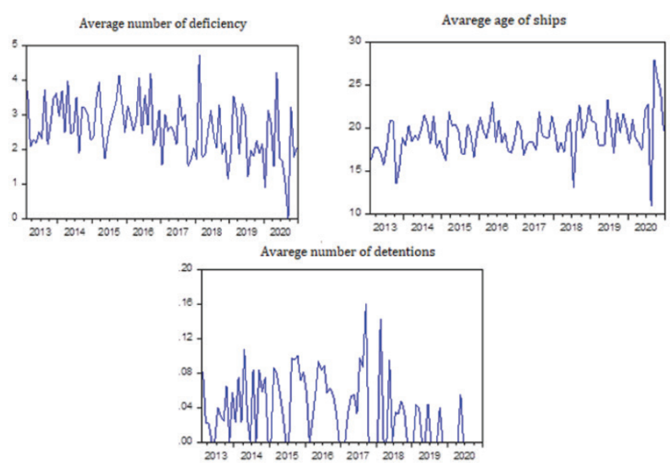

Figure 1. *Variable time course charts*

To prevent the pseudo-regression phenomenon originating from seasonality, the seasonality conditions of the variables should be examined with the seasonality test, and seasonal adjustments should be made if deemed necessary. The seasonality test result in Table 7 shows that there is no seasonal effect for any variable according to the F and Kruskal-Wallis H seasonality test findings, which test the difference between the monthly averages (Sig.>0.10).

Table 8 shows the statistics of the ADF unit root test that was performed to determine the stationarity status of the variables. As evident in the table, the T variables are stationary at the level of 1% significance (Sig.<0.01). On the other hand, while the Y and E variables are not stationary in the level values, they become stationary in the first cyclic differences. When the stationarity states of the variables are examined together, T≈I (0), Y≈I (1), and E≈I (1) definitions can be made. In other words, it can be said that the variables in Equation (9) are stationary in different degrees.

Table 5. *Definitions of variables*

Variables	Symbol
Average number of detention	T
Average age of ship	Y
Average number of deficiencies	E

Table 6. *Descriptive statistics of variables used in the ARDL test*

Descriptive Statistics	T	Y	E
Mean	0.035	19.294	2.596
Maximum	0.160	28.000	4.714
Minimum	0.000	11.000	0.000
Standard deviation	0.038	2.463	0.839
Skewness	0.851	0.115	-0.049
Kurtosis	3.031	5.192	3.083
Jarque-Bera	11.479	19.238	0.065
J.B (Sig.)	0.003	0.001	0.968
Number of observations	95	95	95

J.B (Sig.): T: Average number of detention, Y: Average age of ship, E: Average number of deficiencies

Table 7. *Seasonality tests for variables*

Variables	F (11, 83)		Kruskal-Wallis (11)	
T	1.784	Sig.>0.10	22.854	Sig.>0.10
Y	0.789	Sig.>0.10	8.712	Sig.>0.10
E	0.536	Sig.>0.10	15.419	Sig.>0.10

(Values in the parentheses indicate the test degrees of freedom)

T: Average number of detention, Y: Average age of ship, E: Average number of deficiencies, F: Test for the joint significance of the coefficients

Table 8. *ADF unit root test*

Variables	Augmented Dickey-Fuller test statistics		
	Without constant	With constant	With constant and trend
T	-3.192 [1]***	-7.536 [0]***	-8.101 [0]***
	(0.002)	(0.000)	(0.000)
Y	0.549 [3]	-9.126 [0]***	-9.848 [0]***
	(0.833)	(0.000)	(0.000)
ΔY	-10.841 [2]***	-10.813 [0]***	-10.782 [2]***
	(0.000)	(0.000)	(0.000)
E	-0.645 [4]	-9.135 [0]***	-10.417 [0]***
	(0.435)	(0.000)	(0.000)
ΔE	-8.569 [3]***	-8.524 [3]***	-8.516 [3]***
	(0.000)	(0.00)	(0.000)

***represents stationarity at the significance level of 1%. Parentheses () include the value of probability (p) of the ADF unit root tests. Brackets [] contain the optimal ADF unit root test delay length selected according to the Schwarz Information Criteria. Maximum delay=8. Δ: The first cyclical difference of the variable

Since all the variables used in the research model are not stationary and the variables are seen to be stationary at different orders [I (0) and I (1)], it was decided that the appropriate econometric time-series estimation method to examine the relationship between variables is the ARDL boundary test method.

For the ARDL method, to select the optimal delay lengths for the autoregressive model, the Akaike information criterion gives the command to select the optimal delay, and the program determines the optimal variable delays as follows: 1 for T, 0 for Y, and 2 for E. In this case, the ARDL model can be expressed as ARDL (1, 0, 2).

For the ARDL (1, 0, 2) model, the autoregressive model, error correction model, F limit test statistics, long-term coefficients, and diagnostic test statistics are presented in Table 9. Upon examination, there is no variance problem

Table 9. *ARDL (1, 0, 2) model estimation results*

Results of autoregressive model					
Variables	**β**	**S.H**	**t**	**Sig.**	
T_{t-1}	0.021	0.108	0.188	0.851	
Y	0.001	0.001	0.321	0.748	
E	0.028	0.004	7.633***	0.000	
E_{t-1}	0.008	0.005	1.662	0.101	
E_{t-2}	0.007	0.004	1.497*	0.076	
Constant term	-0.085	0.035	-2.431**	0.017	
Results of error correction model					
Variables	**β**	**S.H**	**t**	**Sig.**	
ΔE	0.028	0.003	9.028***	0.000	
ΔE_{t-1}	-0.007	0.003	-2.185**	0.031	
ECM	-0.979	0.104	-9.393***	0.000	
ΔE	0.028	0.003	9.028***	0.000	
F limit test statistics					
F=2 1,323***		**Significance**	**I (0)**	**I (1)**	
		1%	4.13	5.00	
		5%	3.10	3.87	
		10%	2.63	3.35	
Long-term statistics					
Variables	**β**	**S.H**	**t**	**Sig.**	
Y	0.001	0.001	0.324	0.747	
E	0.044	0.006	7.164***	0.000	
Constant term	-0.087	0.033	-2.609**	0.011	
Diagnostic test					
F test		F (20. 72)=15.152***		Sig.=0.000	
Determination		R2=0.465		D.R2=0.435	
White heteroscedasticity test		F (20. 72)=0.709		Sig.=0.804	
Breusch-Godfrey autocorrelation test		Lag (2)	F (2. 85)=0.069	Sig.=0.971	
		Lag (4)	F (4. 83)=0.518	Sig.=0.723	
		Lag (6)	F (6. 81)=0.481	Sig.=0.821	
		Lag (8)	F (8. 79)=0.395	Sig.=0.921	
		Lag (12)	F (12. 75)=0.651	Sig.=0.792	
Error term	$\bar{X}\approx 0$	J.B=13.436	J.B (Sig.)=0.001	S=0.700	K=4.226

(*, **, and *** represent the significance level of 10%, 5%, and 1%, respectively. The parentheses include the test degrees of freedom.)

ARDL: Auto regressive distributed lag, T: Average number of detention, Y: Average age of ship, E: Average number of deficiencies, ECM: Error correction term, S.H: Standard error in the model according to the white heteroscedasticity test for the autoregressive model [F (20, 72)=0.709, Sig.>0.10]. This step is the first stage of the ARDL model. There is no autocorrelation problem up to the 12th delay in the model according to the Breusch-Godfrey autocorrelation test (Sig.>0.10). The model error terms are distributed with a zero mean without showing any significant distortion (|S|<1). Since the assumptions are provided for the autoregressive model, no loss of efficiency is expected in the model due to the assumption violations. For this reason, there is no need for a resistive standard error estimation.

Results from autoregressive model findings reveal that the Y variable does not have a statistically significant effect on the T variable for the short term (β=0.001, Sig.>0.10). It is seen that the short-term parameter of the E variable on the T variable is statistically significant and positive at the 1% significance level (β=0.028, Sig.<0.01). To be more precise, as the average number of ship deficiencies in the same period increases, the average number of their detentions in the port also increases. On the other hand, there is no statistically significant relationship between the average age of the ship and the average number of ship detentions in the port for the same period.

When the ARDL model F limit test is examined, the variables are found to be in a statistically significant long-term balance relationship at the 1% significance level (F=21,323> $F_{Tab,}$ 0.01). To put it more clearly, the variables in the model have a statistically significant equilibrium relationship in the long-term.

As a result of the long-term equilibrium relationship being significant, it will be meaningful to interpret the long-term parameters. Upon examination, the Y variable does not have a statistically significant effect on the T variable in the long term (β=0.001 Sig.>0.10). The long-term effect of the E variable on the T variable is predicted to be statistically significant and positive at the 1% significance level (β=0.044 Sig.<0.01).

When the ARDL model error correction equation findings are examined, it is seen that the error correction model (ECM) term is statistically significant and negative at the 1% significance level and with an absolute value of less than 2 (ECM=-0.979, Sig.<0.01). In this case, it can be said that the error correction mechanism of the model works. To put it more clearly, it can be said that the deviations from the long-term balance are brought into balance by the error term throughout the periods and return to the long-term balance.

Cusum and Cusum square test graphs drawn for the long-term stability condition of the estimated model are presented in Figure 2. When the graphs are examined, both Cusum and Cusum square test statistics do not significantly exceed the 5% significance band during the period under consideration. For this reason, it can be said that the long-term statistics are stable at the 5% significance level.

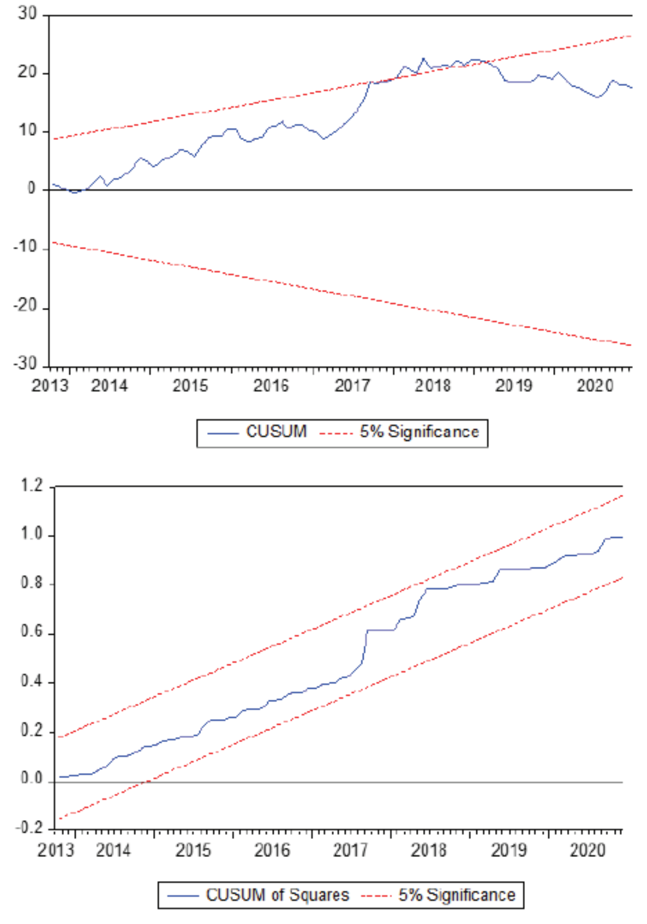

***Figure 2.** Cusum and Cusum square test*

4. Discussion

According to the data frequency distribution tables, although the most detained ship type is the commercial yacht (detention percentage=31.8%, number of detained ships inspected=7 out of 22 detained commercial yachts), the general cargo ships are the most detained ships with a detention percentage of 5.3% (total inspected general cargo is 61 out of 1,142 detained cargo ships). Vessels are generally detained during a more detailed inspection and ships that are 30 years and older are most likely to be detained as seen from the frequency data distributions. Although this is the case, the ARDL analysis reveals that the age of Turkish-flagged vessels does not significantly affect the detention of the Turkish-flagged vessels under the Paris MoU. Data frequency distributions, especially the data on the ship's age, help us create a hypothesis to understand the effect of variables on the ship's detention under the Paris MoU.

The ARDL test is performed to determine whether the variables that present data distribution, especially deficiencies that have been found on the ships and the age of ships, have a significant effect on the number of detentions of Turkish-flagged vessels under the Paris MoU. Results confirmed that the number of deficiencies of the Turkish-flagged vessels significantly affects the number of detentions of the Turkish-flagged vessels under the Paris MoU and the age of the Turkish-flagged vessels does not significantly affect the detention of the Turkish-flagged vessels under the Paris MoU.

According to the ARDL test result, Equation (10) is obtained. A one-unit increase in the number of deficiencies found on Turkish-flagged ships within the scope of the Paris MoU increases the probability of detention of the ship by 0.044 units.

$$T=-0.087+0.044*E \quad (10)$$

In accordance with Cusum and Cusum square tests, autoregressive model, error correction model, F limit test statistics, long-term coefficients, and diagnostic test statistics, the model is fit appropriately and reasonably.

Although there exist many studies that state that the ship's age can significantly affect the number of detentions of the vessels, the opposite result is found in this study, which could be caused by many reasons. One possible reason is the new inspection regime of the Paris MoU. According to the NIR, the company performance regime is treated as a new parameter in the Paris MoU inspections. The company performance formula accounts by taking into consideration items of ISM deficiencies, refusal of access, and risk profiles. Therefore, the company performance and flag states (black-white flag list) are also important factors for the ship's detention. Other possible reasons could be the regulations and conventions in maritime. Since these conventions and rules are developed to prevent any vulnerability of safety, security, and life in the maritime field, and since the PSCs mainly inspect the compliance with the rules of the ships, the vulnerabilities accompanying the increasing age of the ship is automatically removed thanks to these regulations. At this point, the deficiency item is more important than the ship's age. Furthermore, it is seen that multiple studies in the literature have employed binary logistic regression. However, this paper presents the results using an ARDL time-series analysis. This is the first time that the ARDL method is used to identify the effect of the ship's age and the number of deficiencies on the number of detentions of vessels under the Paris MoU. ARDL is a model for capturing long- and short-term causality relationships. Since the unconstrained error correction model is used in ARDL, it has better statistical properties than other time-series tests used to determine the causality between variables, and it gives more reliable results in even small samples. In addition, this paper presents the effective parameters for the detention of Turkish-flagged vessels under the Paris MoU. In this study, the results of the inspections of Turkish-flagged ships are evaluated using the data of the years after the new inspection regime of the Paris MoU. It is proved that the ship profile information affects the inspection frequency and scope rather than the inspection result as stated in many studies.

To summarize, this paper provides empirical results to determine whether the average number of deficiencies that have been found on the Turkish-flagged vessels under the Paris MoU and the average age of Turkish-flagged vessels that have been inspected under the Paris MoU significantly affect the average number of detention decisions of these ships at the port. For this purpose, the ARDL time-series analysis is carried out with recent Turkish vessel inspection data. Particularly, the effect of the number of deficiencies in vessels on the detention, which is among the findings of this study, is a common phenomenon found in almost all studies. Similarly, this study shows that this result has the same effect for Turkish-flagged ships. In contrast with other studies, this study reveals that the ship's age does not have a significant effect on the detention of Turkish-flagged ships. Table 10 summarizes the studies that show whether the ship's age has an effect on the detention or not.

5. Conclusion

This study aimed to analyze the performance measure of Turkish-flagged ships under the Paris MoU PSC. For this purpose, inspection data between 2013 and 2020 of the Paris MoU records are used. In this context, comparison and descriptive analyses are performed to see the data distribution of vessel detention situations according to ship type, age, flag, and inspection type.

It can be concluded that to make a significant contribution to reducing the deficiencies and detentions in PSC inspections, some actions can be performed. For instance, timely reporting of nonconformities detected on ships by the ship's captain and relevant officers to the operator company and the correction of the reported non-conformities by the company as soon as possible can be most important actions Besides, in parallel with the increase in the age of the ship, a tighter follow-up of the general structural condition and timely maintenance-attitudes within the scope of the International Safety Management System can be another significant process for dropping negative results of PSC

***Table 10**. The summary of comparing studies*

The Effect of ship' age on detention of vessels	Authors	Used data	Used method
There is significant effect of ship's age on detention of vessels	Cariou and Wolff [17]	Tokyo MoU inspections data between January 2000 and December 2011	Quantile regression analysis
	Graziano et al. [18]	32206 PSC inspections that are carried out by the European Union and European Free Trade Association Member States within the Paris MoU region from 1 January 2014 to 31 December 2015	Ordinary least square regression model
	Yılmaz and Ece [19]	Inspection results of the Turkish-flagged ships inspected under the Paris MoU between 2011 and 2016	Chi-square test
There is no significant effect of ship's age on detention of vessels	Piniella and Rodriguez-Diaz [20]	The most serious maritime accidents happened in the historical period from the Torrey Canyon incident in 1967 up to the present day in several databases	Descriptive statistics
	Knapp and Franses [21]	The data of 183,819 port state inspections from various port state control regimes for the interval of 1999 to 2004	Binary logistic regression
	Li et al. [22]	Inspection dataset comprising 370,000 inspection cases in 59 countries from January 1999 to December 2008	Binary logistic regression
MoU: Memorandum of Understanding, PSC: Port state control			

inspections. In addition, despite rejecting the hypothesis, which states that the age of the Turkish-flagged vessels significantly affect the number of detentions of the Turkish-flagged vessels under the Paris MoU, it is thought that the renewal of the Turkish maritime merchant fleet and the projects aimed at reducing the average age will contribute to the reduction of detention within the scope of Paris MoU, even if the age of the ship is not taken into account directly within the scope of maritime rules and regulations.

For future studies, it would be beneficial to carry out studies that will analyze factors that affect the detention in PSC inspections applied in other regional control regimes such as the Black Sea MoU, Indian Ocean MoU, Riyadh MoU, Abuja MoU, and the United States Coast Guard. Besides, it can also analyze the effect of other variables such as deadweight tonnage, gross tonnage, class, and company performance on the detention of vessels under both Paris MoU and other regional control regimes. A dynamic modeling system including the variables with a proven effect on the vessels' detention situation can be developed, enabling each company to estimate the probability of detention by entering the data of these variables into the model for each ship. Thus, the optimum benefit can be achieved with less cost since the point where the system is broken is clearly visible.

Authorship Contributions

Concept design: F. Bolat, Data Collection or Processing: F. Bolat, Analysis or Interpretation: F. Bolat, Literature Review: S. Uygur, Writing, Reviewing and Editing: F. Bolat

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Ship-to-Ship Collision Analyses Based on Functional Resonance Analysis Method

I Gde Manik Sukanegara Adhita, Masao Furusho

Kobe University, Graduate School of Maritime Sciences, Kobe, Japan

Abstract

This paper discusses the role of human performance variability in ship-to-ship collisions. Accordingly, an analysis was carried out based on the functional resonance analysis method (FRAM). A ship-to-ship collision report from Indonesia was used to generate the FRAM model for ship-ship encounters. This model was formed using six functions: maneuvering, watchkeeping, bridge communication, bridge-to-bridge communication, bridge-to-port communication, and engine control. Using FRAM, the cause of the collision accident can be determined based on the results of this analysis. This study emphasizes that the emergence of unwanted outcomes results from the unique interaction of the unexpected variability performance of functions between two ships during encounter situations. The resonance phenomenon explained how this unique interaction amplifies the effect of ship operation, performance variability. The use of FRAM could elucidate the complexity in ship operation and provide a more in-depth analysis for ship-to-ship collision accidents.

Keywords

Functional resonance analysis method, Human reliability, Safety-II, Ship-to-ship collision, Maritime accident

1. Introduction

Socio-technical systems, such as a ship, involve complex integration between social (human) and technical components. Each component is expected to function properly every day and meet the desired system goals while ensuring safety onboard. According to the Safety-I perspective, safety is defined as the emergence of an expected event in the system [1]. In contrast, risk is the condition when expected events do not occur. Risk is defined as something unfavorable that causes system failure. The purpose of investigating an accident from the point of view of the Safety-I perspective is to find the cause of that accident and then try to eliminate or create a barrier to it. From this perspective, human error is a critical factor in the occurrence of accidents.

Several prior studies have analyzed human factors regarding situational awareness in ship-to-ship collisions [2-4]. These studies were trying to determine how human error affects the occurrence of ship accidents. One study found that 71% of human error in maritime accidents is affected by poor situational awareness [3]. Furthermore, research regarding situational awareness to prevent ship-to-ship collisions has been done by proposing a model of ship encounter situations to define a risk perception among two ships [5]. Related research has been done by Chauvin and Lardjane about situational awareness. They analyzed the actual decision made by the watch officer to understand the cognitive processes involved in normal ship interaction situations. Besides, they also studied the importance of Bridge Resource Management with a pilot onboard in restricted waters and decisions taken by the captain in critical conditions to enhance situational awareness [2]. Researchers also found that decision-making errors during sailing are caused by three things: a lack of information, incorrect expectations, and an incorrect judgment about the level of attentiveness required [6,7]. However, all of these studies focus only on a single major cause that has the highest contribution to the occurrence of the ship-to-ship collision.

Human error is not the cause of accidents; however, humans play a role in the occurrence of accidents, and their actions are important [8]. Furthermore, technological advancement

Address for Correspondence: I Gde Manik Sukanegara Adhita, Kobe University, Graduate School of Maritime Sciences, Kobe, Japan
E-mail: sukanegaramanik@gmail.com
ORCID ID: orcid.org/0000-0001-8781-8101

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increases the complexity of the system. Humans work according to how they have been trained, but they also tend to adapt and adjust their functioning as per the work requirements. Humans also interpret procedures by associating them with working conditions. However, to cope with this complexity of human behavior, mindsets need to be changed [9].

A systemic model views the accident as the emergence of unusual dependencies within the performance of the system [8]. Failure can be regarded as a variation in the system performance, wherein erraticism of the functional components can be potentially useful or harmful. These variabilities will always exist, no matter what we do. Hence, rather than looking for causes where only a few things go wrong, it is more important to focus on what usually happens in everyday performance when everything goes right. Subsequently, this idea is called the Safety-II perspective.

The functional resonance analysis method (FRAM) was first introduced as a model [10]; later, it was updated and reintroduced as a method [11]. This method was developed to achieve the safety definition listed in the Safety-II perspective. FRAM has been widely used in the field of safety and resilience [12-15]. In the maritime field, a study using FRAM has been conducted to re-analyze the capsizing of the MV Herald of Free Enterprise [16]. Other studies also used FRAM to evaluate the variabilities of system functions in the case of Prestige oil spill [17]. Furthermore, FRAM has been used to model the everyday performance of vessel traffic services to understand resilience from a work-as-done perspective [18].

According to the European Maritime Safety Agency annual report regarding navigational casualties, collision accidents contribute 13% of all maritime casualty events (11 categories) [19]. Therefore, it is become essential to provide a better understanding of ship collision accidents. In this paper, the Safety-II point of view is used through FRAM to provide different perspectives of the occurrence of a ship-to-ship collision. FRAM was used to present dependency among key functions during ship encounter situations. It could show that the accidents occurred due to a combination of unexpected variability from several functions rather than a single primary cause. This study aimed to determine how resonance effect could amplify the variability performance of functions in the system.

2. Ship-to-Ship Collision Accident Data

The maritime sector is a vital industry for global economic trade. The ship is an essential component of the maritime sector. Around 80% of our daily goods are transported by ships [20]. When the ship fails, it has a social, financial, and environmental impact on the transport process. It is necessary to achieve successful sailing activities, maintain the stability of the economy, and protect the ocean environment and people who work on the ship.

Ship-to-ship collisions vary depending on the types of ships involved, weather conditions, location, time, etc. Since it is difficult to generalize their situations, this research limited the scope of analysis to accidents involving merchant ships only. An accident that occurred in Indonesia was chosen for analysis. This report included two ship-to-ship interactions, one of which was successful, and the other was unsuccessful. This report was ideal for presenting the FRAM perspective, wherein success and failure are regarded coming from the same source.

2.1. Case Study

On June 28, 2015, a ship-to-ship collision occurred in Surabaya West Access Channel (SWAC), Indonesia. The encounter situation involved three cargo ship, namely, Ship A, B, and C [21]. The story began when Ship A sailed by Pilot A embarked at about 22:00 local time. At the time, the pilot, master, and some officers were onboard. Her heading was 198° T toward International Container Terminal in the SWAC. Conversely, at about 22.52 local time, Ship B began to sail from Nilam Port in Gresik toward the Kalbut Port in Situbondo. There were four people onboard: Pilot, master, chief officer, and helmsman. Since the accident only involved Ships A and B, the detailed information of Ship C is not included in the report. At that time, Ship C was also sailing on SWAC with master and helmsman onboard. At approximately 23:12 local time, Pilot A realized the existence of Ships C and B. Quickly, Pilot A communicated with Ships B and C regarding passing agreement. Pilot A suggested passing red-to-red with Ship B and green-to-green with Ship C. The first interaction occurred between Ship A and Ship C, wherein the collision was successfully avoided. Then, right behind Ship C, Ship B was ready for the second encounter with Ship A. However, shortly before this second interaction, Pilot A and the crew of Ship A lost their awareness and allowed Ship A to sail into shallow water. The rudder failed, and Ship A lost control of her course. Pilot A quickly took action by informing the situation to Master B in the hope that Ship B could adjust to avoid collision with Ship A. Unfortunately, this time, the distance between Ships A and B was too close; hence, the collision could not be avoided.

3. Functional Resonance Analysis Method (FRAM)

FRAM is a recently developed method for analyzing complex socio-technical systems. The essential feature of this method is a function necessary to explain the activity of a system where the functions are mutually dependent. System activity is modeled in terms of how the system performs to ensure that it performs reliably and systematically [11]. FRAM is based on four basic principles: the principle of equivalence of successes and failure, the principle of approximate adjustments, the principle of emergence, and the principle of functional resonance.

The principle of equivalence of successes and failures states that whether things go right or go wrong, the events arise from the same source, which is the everyday work of the system. While a person is working, his or her performance serves as a source for the system to produce either good or bad outcomes. Humans also can adjust their performance in a dynamic work environment. Here the principle of the approximate adjustment was applied. In the actual work environment, performance needs to be variable to help the system successfully adapt to the operational situation. The principle of emergence shows that system outcome is explained as the emergence of variability in performance from everyday adjustment rather than a result of specific cause-effect chains. The last principle, the principle of functional resonance, describes the ability to detect the unintended interaction amid the variability of function performance through the phenomenon of resonance.

FRAM's functions are divided into three main groups: human, technological, and organizational. Functions describe activities or actions (more than just a task) and show what needs to be accomplished, regardless of the method used. The function has six different aspects, as shown in Figure 1 [11]: input (I), output (O), precondition (P), resource (R), time (T), and control (C) [10]. Descriptively, the I is information, matter, or command used by the function to produce the O. The O describes the action of the function after processing information from other aspects, such as processing instructions from the I. The P specifies the condition that must be achieved before the function starts. However, this does not mean that this signal can start the function by itself. A R is described as something that the function needs while it is being carried out; for example, a spoon for eating ice cream. C refers to something that directs the function while producing the desired O. Finally, time represents an action that consumes time, which can affect the performance of a function.

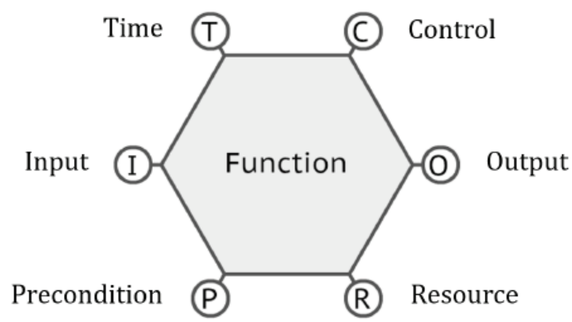

Figure 1. *FRAM hexagonal function representation [11]*

FRAM: Functional resonance analysis method

3.1. Method Implementation

This research used the term sailing to describe the ship's activity moving through the shipping lane for transferring goods from one port to another port. There are three steps in order to conduct the analysis. First, the analysis involved dividing the onboard activity of an officer during sailing into six main functions, as shown in Figure 2, consist: maneuvering (MAN), watchkeeping (WAT), bridge communication (BCM), bridge-to-bridge communication (BBC), bridge-to-port communication (BPC), and engine control (ECN).

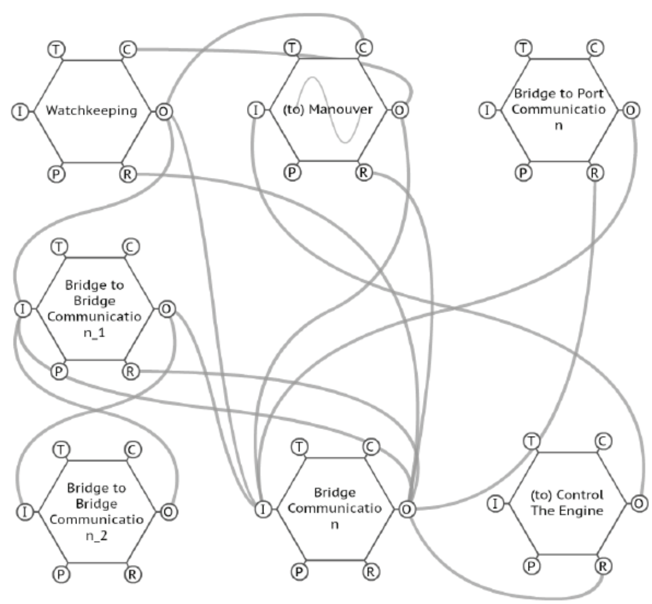

Figure 2. *FRAM general model of human activities during ship-ship encounter*

FRAM: Functional resonance analysis method, T: Time, I: Input, O: Output, C: Control, P: Precondition, R: Resource

MAN describes all activities related to changing the ship's course, which is usually completed by the helmsman but can also be fulfilled by a master or officer on duty or pilot onboard under special conditions. Both direct lookout and lookout through electronic devices (WAT) are used to observe the vicinity of the ship (utilizing direct and electronic devices). BCM is associated with bridge team activities, which also include a pilot (supplementary). This activity describes the on duty crew interaction during sailing. On the bridge, at least one officer and a helmsman are usually present. In some conditions, an additional crew is required on the bridge; for example, the shipmaster should be ready on the deck near the port or channel. BBC describes the interaction between two or more ships to exchange information. Essentially, BBC, BPC, and vessel traffic services (VTS) communication are the same, but bridge-to-port and VTS communications are interactions established between the ship and shore facilities (VTS and port authorities). ECN is an activity carried out under specific situations, such as an emergency condition that forces the ship to lower its service speed or stop the engine.

The second step is to present potential couplings among the functions to describe the system. Figure 3 depicts the integration models of these eight functions. It is essential to state the upstream and downstream functions to describe the temporal relationship between them. This state is explained, as shown in Table 1, where function 1 contains the upstream functions and function 2 contains the downstream functions. It is also crucial to highlight that the relationship between functions does not represent the sequence of actions. The model was built based on the accident report used in this research (work-as-done) combined with the ideal condition imagined by the authors (work-as-imagine).

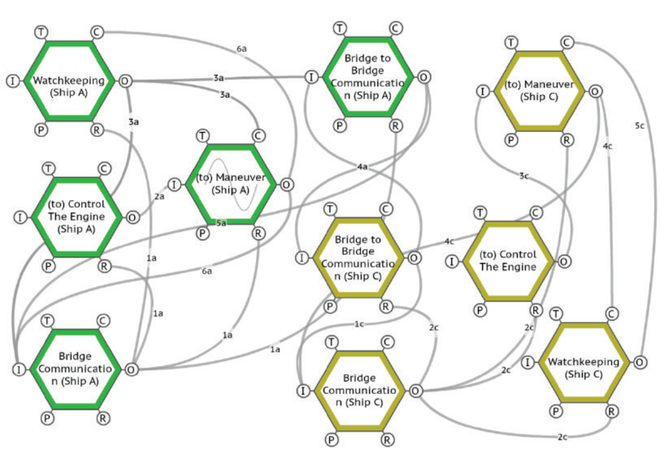

Figure 3. *FRAM model for the first meeting between Ship A and Ship C*

FRAM: Functional resonance analysis method, T: Time, I: Input, O: Output, C: Control, P: Precondition, R: Resource

Table 1. *Function description for the general model*

Code	Function 1	Function 2	Information
1	BCM (O)	MAN (R)	Officer on duty
		ECN (R)	Officer on duty
		WAT (R)	Officer on duty
		BBC (R)	Officer on duty
		BPC (R)	Officer on duty
2	ECN (O)	MAN (I)	Standby
3	WAT (O)	MAN (R)	Observation (electronic device/ direct)
		BCM (I)	Realized the existence of any suspicious ship
		BBC (I)	Realized the existence of any suspicious ship
4	BBC_1 (O)	BBC_2 (I)	Make contact/confirmation
	BBC_2 (O)	BBC_1 (I)	Make contact/confirmation
5	BBC (O)	BCM (I)	Confirm agreement
6	MAN (O)	BCM (I)	Altering the ship's course
		WAT (C)	Altering the ship's course
7	BPC (O)	BCM (I)	Information

MAN: Maneuvering, ECN: Engine control, WAT: Watchkeeping, BCM: Bridge communication, BBC: Bridge-to-bridge communication, BPC: Bridge-to-port communication, O: Output, R: Resource, I: Input, C: Control

The third step is to define the functional resonance based on the dependencies among the functions. Functional resonance is defined as a detectable signal that emerges from an unintended interaction of performance variability between multiple functions. In FRAM representation, couplings are generally many-to-many (rather than one-to-one). For instance, a bridge team communication (code 1) has an O of five functions that serve as a R. Similarly, a function can also have multiple Is from several functions in the form of I, T, Rs, etc. Through this connection, a resonance effect can describe function interactions that either produces damping or amplifying effects for the system performance variability, resulting in desired or unwanted outcomes.

4. Ship-to-Ship Collision Analyses Results

This case study was divided into two parts for analysis. The first part was the first encounter that occurred between Ship A and Ship C, as depicted in Figure 3. The second part was the meeting that occurred between Ships A and B, as shown in Figure 4. The model was built using the report in subsection 2.1 and a step from section 3. It consisted of five functions for each ship, without a BPC. These two models present the dependencies of the function that produce both desired outcome (success to avoid the collision) and undesired outcome (failed to avoid the collision).

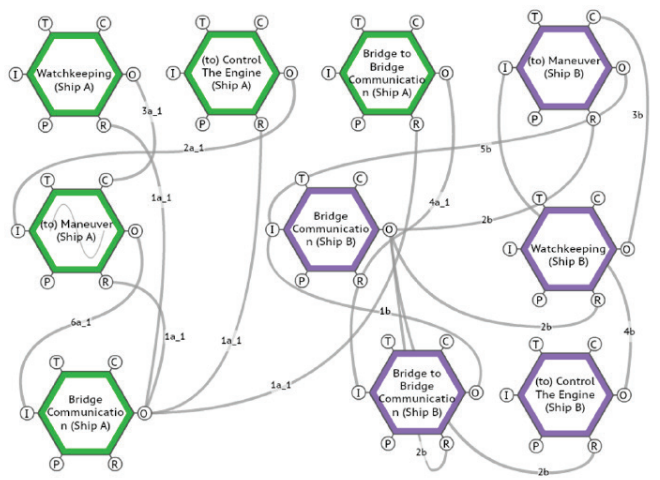

Figure 4. *FRAM model for the second meeting between Ship A and Ship B*

FRAM: Functional resonance analysis method, T: Time, I: Input, O: Output, C: Control, P: Precondition, R: Resource

Table 2 presents detailed information shown in Figure 3. At the first meeting, no accidents occurred. Both Ships A and C passed each other safely. Figure 3 shows that both BCM functions (1a, 2c) from Ships A and C emerged on time and were acceptable. Here, BCM O serves as a R for MAN, ECN, BBC, and WAT. Through these connections, the expected variation of BCM provides a damping effect to the performance variability of its downstream function. The expected variation in WAT (proper watchkeeping) and BBC (Pilot A's decision to make verbal communication with Ships B and C) can emerge smoothly. This emergence also provided positive feedback for BCM.

Everything was on point until Pilot A took action to respond to the passing agreement by altering Ship A's course. At this point, MAN_A (6a) appears to have executed slightly imprecise. BCM receives the O from this function as I. However, for the first meeting, this improper emergence had no significant impact on system performance. Here, we can see that Pilot A and Ship A's crew awareness (1a and 3a) and the decision to make verbal communication (4a) dampened the amplifying effect from MAN_A and muffled the variability of Ship A's performance. This intended interaction of useful variation from these three functions made the variability performance of Ship A easier to manage. Hence, Ships A and C safely pass each other. Ship A should pass Ship B shortly after interacting with Ship C. Figure 4 depicts the FRAM model for the second meeting with detailed information shown in Table 3. Here, Ship A failed to avoid collision with Ship B. As previously stated, the presumed unintended action first occurred at MAN_A (6a). Using the phenomenon of resonance, when two or more objects

Table 2. *Function description of the model for the first meeting*

Code	Function 1	Function 2	Description
1a	BCM_A (O)	MAN_A (R)	Officer on duty
		ECN_A (R)	Officer on duty
		WAT_A (R)	Officer on duty
		BBC_A (R)	Officer on duty
2a	ECN_A (O)	MAN_A (I)	Standby
3a	WAT_A (O)	MAN_A (R)	Observation (electronic device/direct)
		BBC_A (I)	Realized the existence of any suspicious ship
		BCM_A (I)	Realized the existence of any suspicious ship
4a	BBC_A (O)	BBC_C (I)	Make contact/confirmation
	BBC_C (O)	BBC_A (I)	Make contact/confirmation
5a	BBC_A (O)	BCM_A (I)	Confirm agreement
6a	MAN_A (O)	BCM_A (I)	Altering the ship's course
		WAT_A (C)	Altering the ship's course
1c	BBC_C (O)	BCM_C (I)	Confirm agreement
2c	BCM_C (O)	MAN_C (R)	Officer on duty
		ECN_C (R)	Officer on duty
		WAT_C (R)	Officer on duty
		BBC_C (R)	Officer on duty
3c	ECN_C (O)	MAN_C (I)	Standby
4c	MAN_C (O)	BCM_C (I)	Altering the ship's course
		WAT_C (C)	Altering the ship's course
5c	WAT_C (O)	MAN_C (R)	Observation (electronic device/direct)

MAN: Maneuvering, ECN: Engine control, WAT: Watchkeeping, BCM: Bridge communication, BBC: Bridge-to-bridge communication, BPC: Bridge-to-port communication, O: Output, R: Resource, I: Input, C: Control, A: Ship A, C: Ship C

coincide, they vibrate at the same frequency, which can increase the vibration amplitude of one of these objects. When this condition continues to occur within a certain period, the amplitude becomes larger and may cause severe damage or even destroy the system.

The imprecise variation of MAN_A (6a) was followed by an imprecise variation of BCM_A (1a_1) and WAT_A (3a_1). The imprecise variation of BCM_A and WAT_A functions was proven by Pilot A completely lost his awareness (nor Ship A's crew onboard), and all crew onboard do not properly work together as a team. The unintended interaction caused by unexpected variability of these three functions coincidentally became resonant, resulting in large variability of system performance. Ultimately it caused an unexpected event to emerge; in this case, the rudder of Ship A hit the obstacle and failed.

***Table 3.** Function description of the model for the second meeting*

Code	Function 1	Function 2	Description
1a_1	BCM_A (O)	MAN_A (R)	Officer on duty
		ECN_A (R)	Officer on duty
		WAT_A (R)	Officer on duty
		BBC_A (R)	Officer on duty
2a_1	ECN_A (O)	MAN_A (I)	Standby
3a_1	WAT_A (O)	MAN_A (R)	Observation (shallow water undetected)
		BCM_A (I)	Observation (shallow water undetected)
4a_1	BBC_A (O)	BBC_B (I)	Make contact/confirmation
6a_1	MAN_A (O)	BCM_A (I)	Altering the ship's course (failed)
1b	BBC_B (O)	BCM_B (I)	Information (emergency condition)
2b	BCM_B (O)	MAN_B (R)	Officer on duty
		ECN_B (R)	Officer on duty
		WAT_B (R)	Officer on duty
		BBC_B (R)	Officer on duty
3b	WAT_B (O)	MAN_B (R)	Observation (electronic device/ direct)
4b	ECN_B (O)	MAN_B (I)	Stop the engine
5b	MAN_B (O)	BCM_B (I)	Altering the course (cannot stop the ship)

MAN: Maneuvering, ECN: Engine control, WAT: Watchkeeping, BCM: Bridge communication, BBC: Bridge-to-bridge communication, BPC: Bridge-to-port communication, O: Output, R: Resource, I: Input, C: Control, A: Ship A, B: Ship B

On the other hand, Ship B experienced the same condition. Even though the information between Ships A and B was established regarding the passing agreement, Pilot B and Ship B's crew did not maintain their teamwork. This improper variation of BCM_B (2b) was later followed by the emergence of unexpected variability performance of WAT_B (3b) and ECN_B (4b). The O from BCM_B, WAT_B, and ECN_B is received by MAN_B as a R, C, and I. Through this unexpected interaction of functions result in an amplifying effect on the variability performance of Ship B; thus, Ship B was unable to take proper MAN action to overcome Ship A's condition. Both Ships, A and B, failed to avoid the risk of ship-to-ship collision.

5. Discussions

The FRAM has been widely used to provide a better understanding both for accident analysis or everyday operation analysis in the maritime field [17,18]. These studies elaborate on the use of functions and their performance variability to evaluate oil spill accidents and VTS operations. Besides, a study that evaluates dynamic factors in ship operations found that the combination of environmental factors and officer's situational awareness could significantly affect the ship operation [22]. In line with those studies, the present research uses functions and their performance variability to evaluate ship-to-ship collision accidents through FRAM. The analysis is advanced by presenting a FRAM model to present functions dependency for each ship. This research also found the interaction between the officer's situational awareness, ship MAN, and communication play an essential role in ship safety.

The FRAM analysis shows how performance variability of different functions within the same dependencies of functions (Figure 3 and 4) could produce different outcomes for ship encounter situations. In the first encounter, unwanted variability performance from MAN_A O that was received by BCM_A as I could dampen by wanted variability performance from the O of WAT_A and BBC_A that was also received by BCM_A as I. Thus, BCM_A can still produce an acceptable O for its downstream functions. In contrast, the second encounter shows how dependency between the O from BCM_B, WAT_B, and ECN_B that was received by MAN_B as a R, C, and I, respectively, became resonant and amplified the variability performance of MAN_B and MAN_A, resulting in a collision accident for both Ships A and B.

This analysis clearly shows how things go wrong, and things go right are happens exactly in the same way, in this case, from the everyday work (performance variability) itself [11]. This study also shed light on the interaction among officer's actions during ship-ship encounter situations that create either safe or dangerous encounter situations. The results found that the collision accident occurred not due to improper variation from one function but as a result of the unique interaction of unexpected variability performance between many functions [16]. In this case, the emergence properties are crucial in describing the relationships among ship operation functions. The interaction of unexpected variability performance between various functions in everyday ship operation can produce a new outcome beyond their functions capacity. Through functional resonance, the FRAM function and aspect show how the dependency among functions can produce either amplifying or damping effect on the variability of the system performance-the higher the variability performance of the system, the more difficult it is to manage their outcomes.

FRAM considers two phenotype configurations in a simple solution to categorize variability manifestation, namely: timing and precision. Concerning functions that have multiple potential couplings, such as BBC and WAT, are the points where variability can easily amplify and spread. This implies that these functions naturally exhibit highly variable performances. In terms of timing and precision, slight differences in response can cause the system to produce different results.

In contrast, ECN is a function with the lowest variability performance. These functions became active only after the conditions required for the preceding functions were met. Nonetheless, this function is necessary and essential. When the situation becomes dangerous, this function can be used to neutralize the amplifying effect of the system performance and provide a better resolution. Besides, BBC, BPC, and MAN have a moderate levels of variability in function performance. BBC and BPC are more reactive to timing, while MAN is more reactive to precision. A slight distortion of these functions is easier to overcome when others emerge correctly.

Some combinations allowed one function to become distorted if the others emerged precisely in place. The resonant effect can slightly amplify the system performance variability; however, in general, it dampens. For instance, the first encounter between Ships A and C appears to have performed smoothly. The analysis found a slight distortion in the MAN function of the performance of Ship A, as shown in Table 4. This slight distortion did not affect the first encounter.

Table 4. *Key functions that produce a damping effect at the first encounter*

Code	Function	Variability performance classification	
		Time	Precision
1a	BCM_A	Acceptable	Precise
3a	WAT_A	Acceptable	Precise
4a	BBC_A	Acceptable	Precise
6a	MAN_A	Acceptable	Slightly imprecise
WAT: Watchkeeping, BCM: Bridge communication, BBC: Bridge-to-bridge communication, MAN: Maneuvering, A: Ship A			

On the other hand, some combination of variability performance can completely distort the system. For instance, the unexpected variability performance of MAN function in Ship A that occurred in the first encounter situation continues to consume. This minor distortion becomes more prominent over time and has a significant impact on the second encounter. Together with the unwanted variations in WAT and BCM functions, as shown in Table 5, both in Ships A and B become resonant and amplify system performance variability. This condition forces the system to produces a vast amount of possible outcomes. It causes the unexpected outcome easier to emerge. Hence, Ships A and B in the second encounter cannot avoid the collision.

Table 5. *Key functions that produce an amplifying effect at the second encounter*

Code	Function	Variability performance classification	
		Time	Precision
6a	MAN_A	Acceptable	Slightly imprecise
1a_1	BCM_A	Too late	Slightly imprecise
3a_1	WAT_A	Too late	Imprecise
2b	BCM_B	Too late	Imprecise
3b	WAT_B	Too late	Imprecise
WAT: Watchkeeping, BCM: Bridge communication, MAN: Maneuvering, A: Ship A, B: Ship B			

6. Conclusion

Through FRAM analyses, this study found that a single failure of function does not cause a ship-to-ship collision; rather, the unintended dependency of several malfunctions—the interaction between WAT, BCMs, and MAN functions—have a negative impact on the system performance. FRAM analysis facilitated the review of dependencies through resonance phenomena. Function performance exhibited variations that were viewed as either useful or harmful to the system. The dependency among function variability was intended to produce a damping effect on each other. Hence, it was expected that the variability in the system performance would be as low as possible, and system outcomes were controlled. Unfortunately, it was found that the variable performance under certain circumstances is uncontrolled due to the resonance effect between functions. This resonance phenomenon amplified the variability in system performance and made the system difficult to control. In a ship-to-ship interaction, as discussed in this paper, FRAM has shown how the dependency between expected variability performance of each function can dampen the variability in the system performance and prevent the ship from colliding. However, a better understanding of everyday sailing performance is needed to recommend changes that enhance ship safety.

This study provides an in-depth analysis of ship-to-ship collision accidents through functions and their variability performance. Controlling the performance variability is key to managing the system outcome. Functions in the system are expected to emerge acceptably rather than precisely. Although precise action is required, an acceptable action is more likely to occur. Admittedly, human capacity allowed us to create this situation. In this work, FRAM showed excellent potential for ship-to-ship collision analysis by considering the interdependency between functions and searching for potential sources of functional resonance to overcome the emergence of unwanted variability in function performance. Moreover, it must emphasize that a missing function might exist due to a lack of information on the current accident report; thus, further analysis is needed to evaluate this matter. In the future, a quantification approach is also required to provide a better understanding of performance variability.

Authorship Contributions

Concept design: I.G.M.S. Adhita, M. Furusho, Data Collection or Processing: I.G.M.S. Adhita, M. Furusho, Analysis or Interpretation: I.G.M.S. Adhita, M. Furusho, Literature Review: I.G.M.S. Adhita, M. Furusho, Writing, Reviewing and Editing: I.G.M.S. Adhita, M. Furusho.

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Occupational Risk Assessment Using Spherical Fuzzy Safety and Critical Effect Analysis for Shipyards

Fatma Kutlu Gündoğdu[1], Seyed Amin Seyfi-Shishavan[2]

[1]National Defence University, Turkish Air Force Academy, Department of Industrial Engineering, İstanbul, Turkey
[2]İstanbul Technical University, Department of Industrial Engineering, İstanbul, Turkey

Abstract

Today, occupational health and safety is a prominent issue in all branches of the industry. In Turkey, shipyards are highly prone to accidents related to occupational safety. Clearly defining hazard risks and taking precautions against identified priority risks are essential in preventing these risks. This study proposes a two-stage risk-assessment method based on spherical fuzzy sets (SFSs), which is a new fuzzy set theory. A systematic risk-assessment tool with the SFSs was developed combining two of the most reliable decision-making methods: "Analytical hierarchy process (AHP)" and "VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR)." The proposed method was applied in a real case study considering the shipyards in Turkey. Results showed that the developed two-stage risk-assessment approach provides reasonable results in identifying high-risk hazards to ensure occupational safety in a shipyard. A sensitivity analysis was conducted to show the reliability and validity of the results.

Keywords

Shipyard accidents, Risk assessment, Spherical fuzzy safety and critical effect analysis, AHP, VIKOR

1. Introduction

In the recent competitive world, shipyards have to check their production processes to decrease breakdowns and retain their competitive power. Injuries, death, and work loss can be the results of failures. Thus, shipyards must identify and reduce risks in their production system. To perform this procedure, a wide-ranging process analysis must be performed, and reasons for failures must be identified [1]. In addition to safety and health, occupational injuries can also impact economies due to high costs related to work injuries [2]. Taking into account the importance of the abovementioned issues, the concept of occupational health and safety (OHS) can be considered. OHS can be defined as the investigation and identification of hazard risks that may harm employees' health and taking precautions to control these hazard risks [3]. In other words, OHS comprises methodical studies to protect workers from hazardous conditions and circumstances that might be caused by diverse reasons while performing a job in a working environment [4].

One of the key roles in the field of OHS is risk assessment (RA). Indeed, the desired occupation's risk analysis has fundamental and crucial importance in the OHS studies. RA is recognized as the procedure of classifying, assessing, and ranking risks in organizational assets and operations [5]. In another definition by Rausand and Haugen [6], the differences between risk analysis and risk evaluation are explained. Risk analysis is the methodical employment of on-hand information to find out hazards whereas risk evaluation contains decisions on the acceptability of the risk in terms of some important criteria. The entire procedure of risk analysis and risk evaluation is termed RA. RA identifies reasons for risks and suggests control measures to put into action before an injury occurs [7]. An RA procedure comprises the following steps [8,9]:

1. Identify hazards: To identify all hazards and situations that could cause any harm or loss.

Address for Correspondence: Fatma Kutlu Gündoğdu, National Defence University, Turkish Air Force Academy, Department of Industrial Engineering, İstanbul, Turkey
E-mail: kgundogdu@hho.edu.tr
ORCID ID: orcid.org/0000-0001-6746-6014

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2. Decide who might be harmed and how: To determine who and how one might be harmed in each hazard.

3. Decide on precautions based on risk evaluation: To examine the degree of risk that may arise from undesirable events.

4. Record findings and implement them: To implement the results of RA into training.

5. Observe the RA and update if necessary: To review what you do and on go basis. The process may go differently than planned. Thus, we should observe the results and update them if necessary.

Various risk-assessment techniques are present in the literature with their definite characteristics and outcomes. The most used risk-assessment methods are given below with short definitions [10]:

- Hazard and operability study: It can be defined as the systematic identification of hazards in a process plant design.
- Fault tree analysis: It is a potentially quantitative risk analysis method to analyze contributors' details to the main annoying events.
- Event tree analysis: To potentially use quantitative methods to analyze the details of the development of major unwanted events.
- What-if analysis: What-if questions are asked about what could go wrong and what would happen if things go wrong.
- Failure mode and effect analysis (FMEA): It is used to recognize potential failures and discover effects that the failures would inflict.

An industry has to be familiar with some important definitions before implementing one of the risk-assessment methods.

1. Acceptable risk level: The risk level that does not cause damage to human resources or work equipment.

2. Risk: The possibility of failure, injury, or any other destructive result caused by danger or hazard.

3. Hazard: A situation with the potential to lead to injury in the human body and/or damage to the business.

The Fine-Kinney method is a traditional OHS risk-assessment method that yields risk scores and obtain each hazard's risk classes [11]. This method was introduced by Kinney and Wiruth [12] and is a comprehensive and quantitative approach to support managers in evaluating and controlling hazard risks. This method is utilized to determine the ranking of the accomplishment of measures and resource employment according to the ranking of risks. Many researchers in various fields have employed this method. Ilbahar et al. [4] developed a new integrated method, including the Fine-Kinney, Pythagorean analytical hierarchy process (AHP), and a fuzzy inference system for the RA in the field of OHS. Oturakçı et al. [13] developed a new methodology for the Fine-Kinney method used in the construction industry. The integration of the fuzzy AHP (FAHP), fuzzy VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) (FVIKOR), and Fine-Kinney methods was proposed by [14] to control the ballast tank maintenance. In another research, Kokangül et al. [14] combined the AHP method to find hazards and the Fine-Kinney method's priorities to assess a production company's hazard risks. Wang et al. [15] introduced a fuzzy Fine-Kinney framework in which the extended MULTIMOORA method is developed to appraise the risk of ballast tank maintenance. Gul and Celik [16] analyzed the risks of transportation systems by proposing a hybrid Fine-Kinney method. A new Fine-Kinney-based risk-assessment framework integrating the FAHP and FVIKOR approaches was proposed by [17]. Moreover, Yılmaz and Ozcan [18] proposed a risk evaluation and ranking application integrated with the AHP and Fine-Kinney methods to get risk values for lifting vehicles used in building sites. Karasan et al. [19] developed a novel approach and its extension with the Pythagorean fuzzy sets by incorporating the FMEA and Fine-Kinney parameters to provide a comprehensive and accurate RA. Gul et al. [20] presented a novel fuzzy-based method utilizing the FAHP and FVIKOR methods to find the parameters' weights and priorities of hazards in the Fine-Kinney risk-assessment approach for the construction of wind tribunes. In a comprehensive study, Gul et al. [21] investigated the Fine-Kinney method and its fuzzy extensions, approaches, case studies, and Python applications. Gul et al. [22] proposed a Fine-Kinney based occupational RA integrating fuzzy best-worst method and fuzzy multi-attribute ideal real comparative analysis. In another research, Gul et al. [23] extended the Fine-Kinney method to interval type-2 fuzzy sets and the QUALIFLEX method.

Since the industrial revolution and globalization, shipyards and the shipbuilding industry hold a significant trading role [24]. In the last decade, with expansions in the global market, the Turkish shipbuilding industry experienced an increment in shipbuilding and export capacity [25]. Owing to the types of equipment and intricacy of manufacturing processes, the shipbuilding industry is categorized as a heavy industry. Therefore, shipyards must inspect their production processes to reduce failures [1]. As mentioned before, failures cause injury, death, and work loss, which results in the loss of money. For these reasons, shipyards must recognize and reduce risks as much as possible. To realize this, a comprehensive process analysis of the current situation must be performed and reasons for failures must be identified. The variety and harshness of work-related accidents experienced in the shipyards in Turkey have increased over years. Hundreds of serious injuries and even deaths have occurred because of these accidents [26]. The number of occupational fatalities in the Turkish shipyards between 2000 and 2015 is estimated to be approximately 201 [25,26].

In the literature, many essential studies exist with regard to shipyard RAs. Barlas [27] appraised the mortal job-related accidents in the Turkish shipyards and classified them according to fatality reason, age, etc. Lee et al. [28] introduced a RA for the Korean shipyards concerning design, workforce, raw material supply, and risk number. Buksa et al. [29] assessed risk priority numbers based on the FMEA method and recommended reformative actions to reduce the risk priorities. Moreover, Barlas [30] used the AHP method to detect essential safety measures to prevent accidents in the Turkish shipyards. Occupational accidents, accident types, occurrence dates, and sites were investigated in the Japanese shipyards [27].

Additionally, Seker et al. [26] offered a novel occupational risk-assessment method to formulate appropriate precaution strategies to prevent crucial accidents. A risk-assessment technique for the production processes of large-sized steel ship hulls was developed by [31]. Basuki et al. [32] conducted a RA on the construction of new vessels using the Bayesian network approach so that the RA was conducted using a probabilistic value at risk. Moreover, the evaluation of risks using a statistical approach was studied in [33,34].

It is clear that in a risk-assessment procedure, we can face different uncertainties. By integrating risk-assessment approaches into a fuzzy concept, considering any uncertainty can be possible. Fuzzy sets have achieved great success in handling

inexact and imprecise data in various fields [35,36]. Therefore, this paper attempts to formulate an integrated risk-assessment method by compounding the Fine-Kinney, FAHP, and FVIKOR methods using spherical fuzzy numbers to make the RA more effective. Spherical fuzzy sets (SFSs) introduced by Gündoğdu and Kahraman [37] are one of the most popular extensions of the ordinary fuzzy sets in the literature. Unlike the other extensions of the ordinary fuzzy sets such as intuitionistic, Pythagorean, and q-rung orthopair fuzzy sets, which consider just membership and non-membership degrees, SFSs provide a larger preference domain for evaluators, and each decision maker may also assign the membership, non-membership, and hesitancy levels by satisfying the requirement that the squared sum of these levels must be within the unit sphere [38]. SFSs let decision makers have more flexibility in giving different values for uncertainty degrees (membership, non-membership, and hesitancy degrees). The advantage of these fuzzy sets is used for the first time in shipyard risk-assessment analysis, where the uncertainty is high. Further, a new dimension, i.e., "undetectability," has been added to the risk-assessment analysis.

The rest of the paper is organized as follows: Section 2 briefly introduces the basic preliminaries of the Fine-Kinney method and SFSs. In Section 3, the new risk-assessment methodology is presented based on the integration of the spherical FAHP and VIKOR methods. Section 4 presents an application for a case study in the shipyard industry in Turkey. In Section 5, a sensitivity analysis is performed to illustrate the validity of the proposed approach. Finally, the paper is concluded in Section 6 in addition to describing future directions.

2. Preliminaries and Basic Concepts

In this section, the basic information and operations of the Fine-Kinney, FMEA, and SFSs will be explained briefly to make the proposed approach more understandable.

2.1. The Fine-Kinney and FMEA Methods

The Fine-Kinney method is a quantitative risk appraisal tool utilized to mathematically assess and control accidents and hazards [12]. This method is a technique used to determine the rank of accomplishment of measures based on the order of risks and where to use resources first [18]. The risk value is the product of three parameters (C, E, and P), which are introduced as follows [12]:

The severity of consequences for an employee in case of threats or hazards (C): is the most likely result in a potential accident. These values are graded within the interval of (1,100). A high score means that doubt or instability exists about the severity of the incident.

The exposure frequency of the occurrence of threats and hazards (E) : the frequency of the occurrence of a hazard. These values are graded within the interval of (0.5, 10).

The probability of an accident (P) : The likelihood that a hazardous event may occur. These values are sorted within the interval of (0.1, 10).

Therefore, the formula of the risk score (R) is denoted as below;

$$R = C \times E \times P. \quad (1)$$

The probability, frequency, and severity degrees are multiplied using Equation (Eq). (1) to obtain the risk score. These risk scores are classified as "acceptable risk," "risk," "important risk," "high risk," and "very high risk" [12].

FMEA is used to recognize potential failures and discover what effect the failures would have. Thus, an extra dimension exists, which is "undetectability." The present study also incorporated the FMEA into the Fine-Kinney methods to provide an accurate RA. This work developed the new risk-assessment method with SFSs under four risk parameters: probability (P), undetectability (U), consequence (C), and exposure (E).

2.2. Preliminaries of Spherical Fuzzy Sets

Single-valued SFSs are defined in Definition 1. SFSs provide a large preference domain for evaluators by satisfying the unit sphere condition as defined in Eq. (3).

Definition 1. A single-valued SFS $\widetilde{A}_S$ of the universe of discourse X is given by [37]

$$\tilde{A}_s = \{x, \mu_{\tilde{A}_s}(x), \vartheta_{\tilde{A}_s}(x), I_{\tilde{A}_s}(x) \mid x \in X\}, \tag{2}$$

where $\mu_{\widetilde{A}_s}(u)$, $\vartheta_{\widetilde{A}_s}(u)$, *and* $I_{\widetilde{A}_s}(u): U \rightarrow [0,1]$ are the degree of membership, non-membership, and indeterminacy of x to $\widetilde{A}_S$, respectively. Moreover,

$$0 \leq \mu^2_{\tilde{A}_s}(x) + \vartheta^2_{\tilde{A}_s}(x) + I^2_{\tilde{A}_s}(x) \leq 1. \tag{3}$$

Then $\sqrt{1 - \left[\mu^2_{\tilde{A}_s}(x) + \vartheta^2_{\tilde{A}_s}(x) + I^2_{\tilde{A}_s}(x)\right]}$ is defined as the refusal degree of x in X.

Definition 2. Suppose that $\widetilde{A}_s$ and $\widetilde{B}_s$ are two spherical fuzzy numbers that include the membership, non-membership, and indeterminacy degrees. The basic operations of SFSs can then be defined as follows [37] (formulas between 4-7 are given below):

$$\tilde{A}_s \oplus \tilde{B}_s = \left\{\sqrt{\mu^2_{\tilde{A}_s} + \mu^2_{\tilde{B}_s} - \mu^2_{\tilde{A}_s}\mu^2_{\tilde{B}_s}}, \vartheta_{\tilde{A}_s}\vartheta_{\tilde{B}_s}, \sqrt{(1-\mu^2_{\tilde{B}_s})I^2_{\tilde{A}_s} + (1-\mu^2_{\tilde{A}_s})I^2_{\tilde{B}_s} - I^2_{\tilde{A}_s}I^2_{\tilde{B}_s}}\right\} \tag{4}$$

$$\tilde{A}_s \otimes \tilde{B}_s = \left\{\mu_{\tilde{A}_s}\mu_{\tilde{B}_s}, \sqrt{\vartheta^2_{\tilde{A}_s} + \vartheta^2_{\tilde{B}_s} - \vartheta^2_{\tilde{A}_s}\vartheta^2_{\tilde{B}_s}}, \sqrt{(1-\vartheta^2_{\tilde{B}_s})I^2_{\tilde{A}_s} + (1-\vartheta^2_{\tilde{A}_s})I^2_{\tilde{B}_s} - I^2_{\tilde{A}_s}I^2_{\tilde{B}_s}}\right\} \tag{5}$$

$$k\tilde{A}_s = \left\{\sqrt{1-(1-\mu^2_{\tilde{A}_s})^k}, \vartheta^k_{\tilde{A}_s}, \sqrt{(1-\mu^2_{\tilde{A}_s})^k - (1-\mu^2_{\tilde{A}_s} - I^2_{\tilde{A}_s})^k}\right\}; k > 0 \tag{6}$$

$$\tilde{A}^k_s = \left\{\mu^k_{\tilde{A}_s}, \sqrt{1-(1-\vartheta^2_{\tilde{A}_s})^k}, \sqrt{(1-\vartheta^2_{\tilde{A}_s})^k - (1-\vartheta^2_{\tilde{A}_s} - I^2_{\tilde{A}_s})^k}\right\}; k > 0. \tag{7}$$

Definition 3. Spherical fuzzy weighted arithmetic mean (*SFWAM*) with respect to $w = (w_1, w_2, \ldots, w_n)$; $w_i \in [0,1]$; $\sum_{i=1}^{n} w_i = 1$, SFWAM is defined as [37] (8th formula is below):

$$SFWAM_w(\tilde{A}_{S1}, \tilde{A}_{S2}, \ldots, \tilde{A}_{Sn}) = w_1\tilde{A}_{S1} + w_2\tilde{A}_{S2} + \cdots + w_n\tilde{A}_{Sn} = \left\{\sqrt{1-\prod_{i=1}^{n}(1-\mu^2_{A_s})^{w_i}}, \prod_{i=1}^{n}\vartheta^{w_i}_{A_s}, \sqrt{\prod_{i=1}^{n}(1-\mu^2_{A_s})^{w_i} - \prod_{i=1}^{n}(1-\mu^2_{A_s} - I^2_{A_s})^{w_i}}\right\}. \tag{8}$$

Definition 4. Spherical fuzzy weighted geometric mean (*SFWGM*) with respect to $w = (w_1, w_2, \ldots, w_n)$; $w_i \in [0,1]$; $\sum_{i=1}^{n} w_i = 1$, SFWGM is defined as [37] (9th formula is below):

$$SFWGM_w(\tilde{A}_{S1}, \tilde{A}_{S2}, \ldots, \tilde{A}_{Sn}) = \tilde{A}_{S1}^{\ w_1} + \tilde{A}_{S2}^{\ w_2} + \cdots + \tilde{A}_{Sn}^{\ w_n} = \left\{\prod_{i=1}^{n}\mu^{w_i}_{A_s}, \sqrt{1-\prod_{i=1}^{n}(1-\vartheta^2_{A_s})^{w_i}}, \sqrt{\prod_{i=1}^{n}(1-\vartheta^2_{A_s})^{w_i} - \prod_{i=1}^{n}(1-\vartheta^2_{A_s} - I^2_{A_s})^{w_i}}\right\}. \tag{9}$$

3. The Proposed Spherical Fuzzy Risk-Assessment Methodology

In the proposed spherical fuzzy (SF)-AHP&SF-VIKOR methodology, the weights of risk parameters are first calculated using the SF-AHP. These weights are then used in the SF-VIKOR method to find the priorities of hazards. Figure 1 gives the general framework of the proposed methodology.

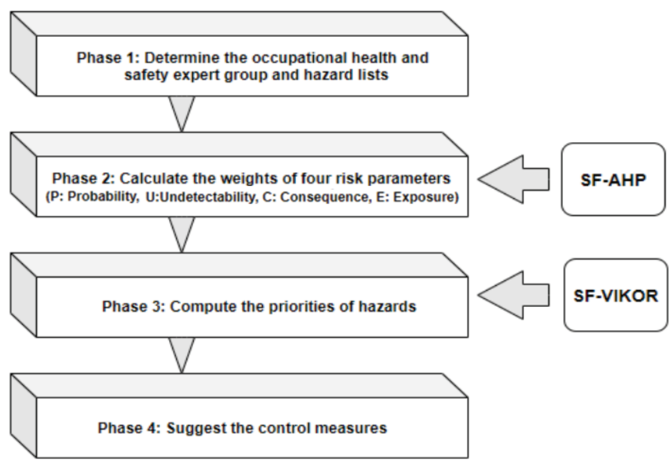

***Figure 1.** The proposed risk-assessment framework*

SF-AHP: Spherical fuzzy analytic hierarchy process, SF-VIKOR: Spherical fuzzy VlseKriterijumska Optimizacija I Kompromisno Resenje

Table 1 indicates linguistic terms to construct pairwise matrices based on SF-AHP and linguistic terms to construct decision matrices based on SF-VIKOR.

Table 1. *Linguistic terms for SF-AHP and SF-VIKOR*

SF-AHP linguistic terms	(μ,ϑ,π)	SF-VIKOR linguistic terms
Absolutely more important (AMI)	(0.9, 0.1, 0.0)	Very high (VH)
Very high important (VHI)	(0.8, 0.2, 0.1)	High (H)
High important (HI)	(0.7, 0.3, 0.2)	Medium high (MH)
Slightly more important (SMI)	(0.6, 0.4, 0.3)	Slightly high (SH)
Equally important (EI)	(0.5, 0.4, 0.4)	---
Slightly low important (SLI)	(0.4, 0.6, 0.3)	Slightly low (SL)
Low important (LI)	(0.3, 0.7, 0.2)	Medium low (ML)
Very low important (VLI)	(0.2, 0.8, 0.1)	Low (L)
Absolutely low important (ALI)	(0.1, 0.9, 0.0)	Very low (VL)
SF-AHP: Spherical fuzzy analytic hierarchy process, SF-VIKOR: Spherical fuzzy VlseKriterijumska Optimizacija I Kompromisno Resenje		

The steps of the methodology are described in detail in the pseudo code as follows:

Pseudo Representation of Spherical Fuzzy Safety and Critical Effect analysis

Input: n: number of evaluation criteria (i *and* j *are aliases* = 1,2, …n), m: number of hazards (h = 1,2, …m), p: number of experts (k = 1,2, …p), o: number of pairwise comparison matrices (s = 1,2, …o)

Stage 1: Spherical FAHP

Output: Weights of the risk parameters

begin for $s = 1{:}o$ **do:**

Step 1.1: Construct the linguistic spherical fuzzy judgment matrices

$(\tilde{R} = (\tilde{r}^{k}{}_{ij})_{n\times n}) \Longrightarrow$ Based on Table 1

Step 1.2: Convert the linguistic terms into corresponding spherical fuzzy numbers $\Longrightarrow$ Based on Table 1

where $\tilde{R} = (\tilde{r}^{k}{}_{ij})_{n\times n} = \left([\mu_{ij}^{k}, v_{ij}^{k}, \pi_{ij}^{k}]\right)_{n\times n}$

for each comparison matrix $\tilde{R}$ **do** consistency analysis:

$CR = \frac{CI}{RI}$ where $CI = \frac{\lambda_{max}}{n-1}$

end for

Step 1.3: Analyze the results of consistency analysis

if $CR > 0.1$:

return to **Step 1.1**

else:

go **Step 1.4**

end if

Step 1.4: Aggregate the spherical fuzzy pairwise matrices and obtain spherical fuzzy weights of the risk parameters using the spherical fuzzy weighted geometric mean operator:

$$\tilde{r}_{ij} = \left\langle \left[\prod_{k=1}^{p} (\mu_{ij}^{k})^{w_k}, \sqrt{1 - \prod_{k=1}^{p} (1 - v_{ij}^{k\,2})^{w_k}}, \sqrt{\prod_{k=1}^{p} (1 - v_{ij}^{k\,2})^{w_k} - \prod_{k=1}^{p} (1 - \mu_{ij}^{k\,2} - v_{ij}^{k\,2})^{w_k}} \right] \right\rangle$$

where weights of experts are $w_k > 0\ (k = 1,2,\ldots,p)$ and $\sum_{k=1}^{p} w_k = 1$ and $(r_{ij})_{n\times n} = \left([\mu_{ij}, v_{ij}, \pi_{ij}]\right)_{n\times n}$

end for

Step 1.5: Defuzzify the weights of the risk parameters to get crisp values

for $j = 1{:}n$ **do:**

$$w_j = \sqrt{\left|100 * \left[\left(2\mu_{ij} - \pi_{ij}/_2\right)^2 - \left(v_{ij} - \pi_{ij}/_2\right)^2\right]\right|}$$

for $j = 1{:}n$ **do** normalization:

$$\overline{w}_j = \frac{w_j}{\sum_{j=1}^{n} w_j}$$

end for

Stage 2: Spherical fuzzy VIKOR

Output: Obtain the priorities of the hazards

for $k = 1{:}p$ **do:**

Step 2.1: Input linguistic decision matrices $\left(\tilde{F}_s^{\,k}\right)_{m\times n}$ by each expert $\Longrightarrow$ Based on Table 1

Step 2.2: Convert these linguistic terms to their corresponding spherical fuzzy numbers (SFN)

where $\tilde{f}_{ij}^{k} == \left([\mu_{ij}^{k}, v_{ij}^{k}, \pi_{ij}^{k}]\right)_{m\times n}$

Step 2.3: Aggregate the SFN influence matrices using the spherical fuzzy weighted geometric mean

$$\tilde{f}_{ij} = \left\langle \left[\prod_{k=1}^{p} (\mu_{ij}^{k})^{w_k}, \sqrt{1 - \prod_{k=1}^{p} (1 - v_{ij}^{k\,2})^{w_k}}, \sqrt{\prod_{k=1}^{p} (1 - v_{ij}^{k\,2})^{w_k} - \prod_{k=1}^{p} (1 - \mu_{ij}^{k\,2} - v_{ij}^{k\,2})^{w_k}} \right] \right\rangle$$

where $w_k > 0\ (k = 1,2,\ldots,p)$ and $\sum_{k=1}^{p} w_k = 1$

end for

Step 2.4: Compute the SFN best value $(\tilde{f}_j^{+})$ and worst value $(\tilde{f}_j^{-})$ based on the following equations:

$$\tilde{f}_j^{+} = \left\{ \left\langle \left[\left(\max_j \mu_{ij}\right), \left(\min_j v_{ij}\right), \left(\min_j \pi_{ij}\right) \right] \right\rangle \middle| i = 1,2,\ldots,n \right\}^T = \{\tilde{f}_1^{+}, \tilde{f}_2^{+}, , \tilde{f}_n^{+}\}^T$$

$$\tilde{f}_j^{-} = \left\{ \left\langle \left[\left(\min_j \mu_{ij}\right), \left(\max_j v_{ij}\right), \left(\max_j \pi_{ij}\right) \right] \right\rangle \middle| i = 1,2,\ldots,n \right\}^T = \{\tilde{f}_1^{-}, \tilde{f}_2^{-}, , \tilde{f}_n^{-}\}^T.$$

Step 2.5: Calculate S_i and R_i degrees

for $i = 1{:}m$ **do:**

2.5.1. Compute (S_i) degree

$$S_i = \sum_{j=1}^{n} \overline{w}_j \left[d(\tilde{f}_j^{+}, \tilde{f}_{ij}) \middle/ d(\tilde{f}_j^{+}, \tilde{f}_j^{-}) \right]$$

2.5.2. Compute (R_i) degree

$$R_i = \max_j \left[\bar{w}_j d(\tilde{f}_j^+, \tilde{f}_{ij}) \Big/ d(\tilde{f}_j^+, \tilde{f}_j^-) \right]$$

where the Zhang and Xu's distance formula is as follows:

$$d(\tilde{f}_j^+, \tilde{f}_{ij}) = \left(\left|\mu_{ij}^2 - (\mu_j^+)^2\right| + \left|v_{ij}^2 - (v_j^+)^2\right| + \left|\pi_{ij}^2 - (\pi_j^+)^2\right| \right)$$
$$d(\tilde{f}_j^+, \tilde{f}_j^-) = \left(\left|(\mu_j^-)^2 - (\mu_j^+)^2\right| + \left|(v_j^-)^2 - (v_j^+)^2\right| + \left|(\pi_j^-)^2 - (\pi_j^+)^2\right| \right),$$

end for

Step 2.6: Calculate the maximum group utility (Q_i)

for $i = 1{:}m$ **do:**

$$Q_i = v \frac{(S_i - S^*)}{(S^- - S^*)} + (1 - v) \frac{(R_i - R^*)}{(R^- - R^*)}$$

where $S^* = \min_i S_i$, $S^- = \max_i S_i$ $R^* = \min_i R_i$, *and* $R^- = \max_i R_i$ and $v = 0.5$

end for

Step 2.7: Rank the alternatives in a descending order Q_i

end

4. Application: Spherical Fuzzy Safety and Critical Effect Analysis for Shipyards

To show the applicability of the proposed approach, a case study was employed to the ship production in Turkey. Shipbuilding contains three processes: design, materials, and production. Each process has different sections. The design process is the initial process that contains the basic design, key plan, yard plan, production drawing, and documentation sections. The materials process is the intermediate part of the shipbuilding that includes the hull construction, paint materials, hull outfitting, machinery, and outfitting. The last process is production that comprises work preparation, hull construction, leak test, hull outfitting, machinery systems, electrical outfitting, painting, corrosion control, and spare parts. Herein, the hazards and associated risks regarding the hull construction in the ship were analyzed. Four risk parameters, i.e., the P, U, C, and E of the hazards were evaluated. To assess eleven different hazard risks and their effects on the safety risk of the observed shipbuilding industry, three decision makers, which are represented as Expert 1, Expert 2, and Expert 3, were used. Table 2 illustrates the hazard list, identifications, and possible effects, and Table 3 presents the linguistic evaluations of the risk parameters. Based on Step 1.4, these evaluations were aggregated as given in Table 3.

Table 4 presents the defuzzified and normalized weights of the main risk parameters that are obtained using Step 1.5. The most essential risk parameter is the probability of hazards' occurrences, which is followed by the exposure of the events parameter.

***Table 2.** Hazard identification list in the shipwrights [17]*

Hazard ID	Hazard Identification	Possible Risk
Hazard 1 (H1)	Working with hand tools	Cuts, injury
Hazard 2 (H2)	Material handling lifting	Joint, injury, discomfort
Hazard 3 (H3)	Layout of the work environment (unfixed materials)	Wound, injury
Hazard 4 (H4)	Rotating or moving parts of the ships	Injury, death
Hazard 5 (H5)	Falling objects	Injury, death
Hazard 6 (H6)	Unsuitable climatic conditions (too cold or too hot conditions)	Disease, injury
Hazard 7 (H7)	Noisy pollution	Hearing less, stress, and panic
Hazard 8 (H8)	Emergency events (flood, earthquake, fire, etc.)	Injury, death
Hazard 9 (H9)	Working with lifting tools	Injury, death
Hazard 10 (H10)	Exposure to chemical liquid, dust, and gas (Painting, acids, etc.)	Cancer, burns, eye disease, irritation
Hazard 11 (H11)	Falling from the ship	Injury, death

The decision matrix in Table 5 is obtained using Step 2.3. After performing Step 2.4, the SF best $(\tilde{f}_j^+)$ and worst $(\tilde{f}_j^-)$ values are obtained and presented in Table 6.

Table 7 shows the ranking result based on the descending order of Q_i values. The first three critical processes/work units in descending order are the material handling lifting (H2), working with the hand tools (H1), and falling objects (H5). The last critical hazard is the emergency events (H8).

To decrease the worst consequences of the riskiest categories (H2, H1, and H5), some control measures can be suggested. The examination of the shipyards in Turkey revealed that the main issues are the insufficient training period with hand tools, handling process, and importance of the usage of protective materials. The training period must be extended to overcome these issues, such as manual lifting, hand tools, and transportation works. Using the height equipment should be reviewed, and the possible damaged items must be changed. Employees must realize the importance of the usage of appropriate protective eyewear, safety gloves, and helmets during work.

5. Sensitivity Analysis by Changing the Weights of the Risk Parameters

A sensitivity analysis is a useful process to test the validity of the method. In this research, a sensitivity analysis was performed on the weights of the risk

Table 3. *Linguistic terms for the risk parameters and aggregation results*

Experts	Risk parameters				Aggregation results		
Expert 1	**P**	**U**	**C**	**E**	μ	v	π
P	EI	HI	AMI	SMI	0.66	0.33	0.28
U	LI	EI	SMI	LI	0.31	0.69	0.23
C	ALI	SLI	EI	VLI	0.33	0.66	0.25
E	SLI	HI	VHI	EI	0.58	0.41	0.29
Expert 2	**P**	**U**	**C**	**E**	μ	v	π
P	EI	VHI	HI	SMI	0.64	0.34	0.28
U	VLI	EI	SLI	ALI	0.25	0.75	0.20
C	LI	SMI	EI	LI	0.41	0.59	0.27
E	SLI	AMI	HI	EI	0.58	0.41	0.29
Expert 3	**P**	**U**	**C**	**E**	μ	v	π
P	EI	HI	SMI	VHI	0.64	0.34	0.28
U	LI	EI	SLI	SMI	0.44	0.55	0.30
C	SLI	SMI	EI	VHI	0.56	0.43	0.30
E	VLI	SLI	VLI	EI	0.30	0.70	0.23

P: Probability, U: Undetectability, C: Consequence, E: Exposure, EI: Equally important, HI: High important, AMI: Absolutely more important, SMI: Slightly more important, LI: Low important, ALI: Absolutely low important, SLI: Slightly low important, VLI: Very low important, VHI: Very high important

Table 4. *Weights of the risk parameters based on SF-AHP*

Risk parameters	μ	v	π	Defuzzified weights	Normalized weights
P	0.65	0.33	0.28	11,3554	0,446
U	0.32	0.68	0.24	1,7795	0,070
C	0.42	0.58	0.28	5,5122	0,216
E	0.46	0.54	0.26	6,8266	0,268

P: Probability, U: Undetectability, C: Consequence, E: Exposure, SF-AHP: Spherical fuzzy analytic hierarchy process

parameters. Different important weights can result in different outcomes. The weights of the risk parameters were changed according to the following weight vector: $w_j = [0.25, 0.25, 0.25, 0.25]^T$ *for* $j = P, U, C, E$. As seen in Table 8, the first and last hazards were the same, whereas the other hazards' ranking changed. This indicates the importance of the first hazard that remains the same for each situation. The first and last hazards were not sensitive to the risk parameters weights, whereas the other alternatives were observed to be sensitive.

This study employed a sensitivity analysis by changing the v value, which combines the S_i and R_i values to get Q_i, which is the value for the ranking of the hazards. The results indicated that the similarities in the given decisions existed. Figure 2 shows the slightly similar decisions from the proposed approach that were produced by performing the sensitivity analysis.

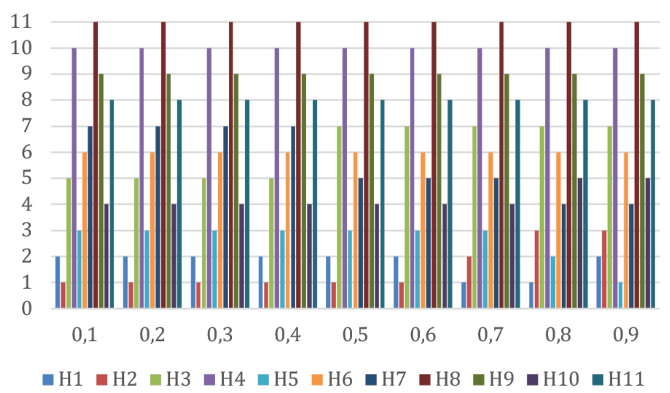

Figure 2. *Sensitivity analysis by changing the v value*

6. Conclusion and Future Research Directions

As in all branches of industry, job-related accidents are a reason for serious social and economic problems owing to physical wounds and deaths. The frequency of fatal accidents in the Turkey's shipyards has forced shipyards to take appropriate actions to improve the safety of the workplace and workforce environment. Therefore, defining, evaluating, and eliminating or reducing risks have become important in reducing fatal and serious occupational injury accidents in shipyards. To this end, the current research presented a hybrid risk-assessment approach combining the safety and critical effect analysis (SCEA), AHP, and VIKOR methods. In the proposed framework, the SFSs were used to model the high uncertainty in the risk evaluation process. The SCEA method was employed to determine the main risk

Table 5. *The decision matrix based on the aggregation results of the three experts*

Hazards	Probability (P)	Undetectability (U)	Consequence (C)	Exposure (E)
H1	(0.83, 0.17, 0.08)	(0.10, 0.90, 0.00)	(0.87, 0.14, 0.06)	(0.66, 0.34, 0.24)
H2	(0.80, 0.20, 0.10)	(0.36, 0.64, 0.27)	(0.80, 0.22, 0.13)	(0.70, 0.31, 0.22)
H3	(0.63, 0.37, 0.27)	(0.40, 0.60, 0.30)	(0.36, 0.66, 0.15)	(0.70, 0.31, 0.22)
H4	(0.16, 0.84, 0.07)	(0.30, 0.70, 0.20)	(0.13, 0.87, 0.05)	(0.90, 0.10, 0.00)
H5	(0.73, 0.29, 0.20)	(0.20, 0.80, 0.10)	(0.77, 0.24, 0.14)	(0.90, 0.10, 0.00)
H6	(0.83, 0.17, 0.08)	(0.70, 0.30, 0.20)	(0.70, 0.30, 0.20)	(0.26, 0.74, 0.17)
H7	(0.90, 0.10, 0.00)	(0.60, 0.40, 0.30)	(0.90, 0.10, 0.00)	(0.16, 0.84, 0.07)
H8	(0.10, 0.90, 0.00)	(0.10, 0.90, 0.00)	(0.20, 0.80, 0.10)	(0.87, 0.14, 0.06)
H9	(0.16, 0.84, 0.07)	(0.16, 0.84, 0.07)	(0.18, 0.82, 0.11)	(0.90, 0.10, 0.00)
H10	(0.73, 0.27, 0.17)	(0.90, 0.10, 0.00)	(0.29, 0.72, 0.16)	(0.77, 0.24, 0.14)
H11	(0.26, 0.74, 0.17)	(0.10, 0.90, 0.00)	(0.20, 0.80, 0.10)	(0.87, 0.14, 0.06)

Table 6. *SF best* $(\tilde{f}_j^{+})$ *and worst* $(\tilde{f}_j^{-})$ *values*

$\tilde{f}_j^{+}$	(0.90, 0.10, 0.00)	(0.90, 0.10, 0.00)	(0.90, 0.10, 0.00)	(0.90, 0.10, 0.00)
$\tilde{f}_j^{-}$	(0.10, 0.90, 0.00)	(0.10, 0.90, 0.00)	(0.13, 0.87, 0.00)	(0.16, 0.84, 0.00)
SF: Spherical fuzzy				

Table 7. S_i, R_i *and* Q_i *values and the ranking results*

Hazards	S_i	Rank	R_i	Rank	Q_i	Rank
H1	0.216258	2	0.095691	2	0.020533	2
H2	0.224669	3	0.083806	1	0.012297	1
H3	0.459935	7	0.170784	4	0.361278	7
H4	0.685757	10	0.414921	9	0.918169	10
H5	0.212026	1	0.109679	3	0.03574	3
H6	0.356692	6	0.235738	6	0.350584	6
H7	0.299090	4	0.268965	7	0.340456	5
H8	0.726081	11	0.445766	11	1	11
H9	0.682779	9	0.414921	9	0.915272	9
H10	0.332185	5	0.176793	5	0.245322	4
H11	0.643978	8	0.363663	8	0.806727	8

Table 8. *Ranking based on the new weights of the risk parameters*

Hazards	Q_i	Rank
H1	0.566932	7
H2	0.019083	1
H3	0.273350	3
H4	0.922319	9
H5	0.307946	4
H6	0.367310	5
H7	0.555584	6
H8	0.993654	11
H9	0.837595	8
H10	0.175302	2
H11	0.940003	10

parameters. Moreover, the SF-AHP method was utilized to find the weight of the risk parameters, and the SF-VIKOR was then employed to obtain the priority of the hazards. To explain the effectiveness of the proposed approach, a case study was employed to ship production in Turkey. Results showed that in the Turkish shipyard industry, material handling lifting, working with hand tools, and falling objects are major risks. Therefore, employers should consider some preventive control measures to reduce human losses. To demonstrate the validity of the proposed method, a sensitivity analysis was performed on changing the weight of the risk parameters and v value; the results were sensitive to the weight of the risk parameters. Moreover, the result showed that the new method is robust and flexible in the application.

For future research, the authors recommend the proposed hybrid method by combining fuzzy inference systems to be used in the RA of construction, medical, operational, or other industries, including situations with high uncertainty and risks. Furthermore, some other MCDM approaches such as TOPSIS, ANP, OPA, and their fuzzy versions can be combined with traditional risk-assessment methods.

Authorship Contributions

Concept design: F. Kutlu Gündoğdu, S.A. Seyfi-Shishavan, Data Collection or Processing: F. Kutlu Gündoğdu, S.A. Seyfi-Shishavan, Analysis or Interpretation: F. Kutlu Gündoğdu, S.A. Seyfi-Shishavan, Literature Review: F. Kutlu Gündoğdu, S.A. Seyfi-Shishavan, Writing, Reviewing and Editing: F. Kutlu Gündoğdu, S.A. Seyfi-Shishavan.

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Modeling and Comparison of Bodrum Gulets' Hull Forms with Round and Transom Sterns

Bülent İbrahim Turan, Mehmet Akman

Muğla Sıtkı Koçman University, Bodrum Maritime Vocational School, Muğla, Turkey

Abstract

Gulets built-in Bodrum region, known as Bodrum gulets, are special and unique yachts with a rich historical background and aesthetic designs. Besides aesthetics, the engineered design is important for such leisure crafts; thus, hull characteristics should be analyzed using a binary approach. In this paper, the hull form characteristics of Bodrum gulets with round and transom sterns are investigated, and parametric models based on geometrical dimensions are developed. In order to obtain reliable results, 20 round stern and 24 transom stern Bodrum gulets are used for the parametric evaluation. Hydrostatic parameters of these models are calculated, and general characteristics such as beaminess and fullness are obtained. Additionally, the Holtrop-Mennen method is also used to estimate the resistance performances of these displacement type hulls. The distinctive or similar characteristics of these types of yachts are presented and compared. Finally, a parametric framework is developed for use in the preliminary design stage of such yachts.

Keywords

Bodrum gulet, Round stern, Transom stern, Hull form, Blue voyage

1. Introduction

Gulets, Tırhandil, and Transom Stern yachts are the three types of boat found in Bodrum region of Turkey [1]. These exclusive leisure crafts are used in Blue Voyage, including a unique route around Bodrum peninsula. During this voyage, gulets and transom stern types of yachts are mostly preferred due to their wide aft deck and ease of usage [2]. On the other hand, gulets classified in sailing yachts are seen as one of the symbols of Turkish maritime culture with their rich historical background and remarkable aesthetic lines. Wooden gulets are diversified based on personalized designs and constructions with different interior architecture solutions, sail, and rigging design in response to customer demands [3]. Despite their rich historical background and distinctive design, there are very few studies on gulet type yachts in literature. Gammon et al. [4] investigated the resistance, seakeeping, and stability characteristics of Turkish gulets and used a genetic algorithm for the hull form optimization. Sarıoğlu and Kukner [5] developed a method to estimate the form factor of Bodrum gulets using numerical tools. They stated that the artificial neural network approach is useful in predicting the form factor hull form during the preliminary design stage. A project aimed to research on Turkish gulets and funded by Scientific and Technological Research Council of Turkey was completed [6]. Within this project, Bodrum gulets are analyzed and optimized. Kınacı [7] modeled the Bodrum type schooner yachts using the 1-prismatic coefficient (Cp) method and developed a computer program to be used in the pre-design phase. The recent gulets are designed with round or transom sterns. The shape of the stern influences the functional properties along with the hydrostatics and hydrodynamic characteristics of yachts. Allroth and Wu [8] numerically investigated the hydrodynamic performances of sailing yachts with different shapes of transom sterns, and they stated that box-shaped transom sterns have a smaller wetted surface area, improved righting moment and reduced wave resistance at high Froude numbers. Şireli and Insel [9] analyzed the resistance performance of transom stern crafts and they found that the transom stern

Address for Correspondence: Bülent İbrahim Turan, Muğla Sıtkı Koçman University, Bodrum Maritime Vocational School, Muğla, Turkey
E-mail: bulentturan@mu.edu.tr
ORCID ID: orcid.org/0000-0001-9690-6955

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remarkably influences the wave and viscous resistances. Doctors [10] investigated the resistance of transom stern monohulls using regression analyses for the ventilation of the stern and the length of the transom hollow based on the experimental data. According to Papanikolau [11], even though the shape of the stern has no direct relatioship with the form of waterlines or sections, the stern form has an effect on flow to the propeller near to the stern part; in an elliptical stern, flow follows the waterlines whereas in transom stern, it follows the direction of the buttocks.

The numerical studies are focused on transom stern analysis, and the studies on gulets in literature do not consider the sub-classes of Bodrum gulets where significant differences in design are found. In this study, first, the historical background of Bodrum gulets is revealed in the hull form evolution perspective, followed by the studies of geometric, hydrostatic, and hydrodynamic characteristics of Bodrum gulets with round and transom sterns. Twenty round stern and 24 transom stern Bodrum gulets are used for the parametric evaluation, and the Holtrop-Mennen method is used for resistance estimations. The obtained results for two different stern types are compared, a novel framework for the preliminary design and engineering phases of these types of yachts is developed within the statistical base. This is the first study showing the numerical comparison of Bodrum gulets with round and transom sterns and provides a design guide in terms of geometrical and hydrodynamic aspects. Within this perspective, this research aimed to contribute identification and development of the hull form characteristics of gulets specific to Bodrum region.

1.1. History of Bodrum Gulets

It is necessary to understand the origin of the term "gulet" and how it came to Turkish to investigate the characteristics of Bodrum gulets. There are various ideas about the emergence of gulet type boats. It is believed that Italians constructed the first gulet in the 1800s [12]. Figure 1 presents transverse section curves of Italian type gulets [13].

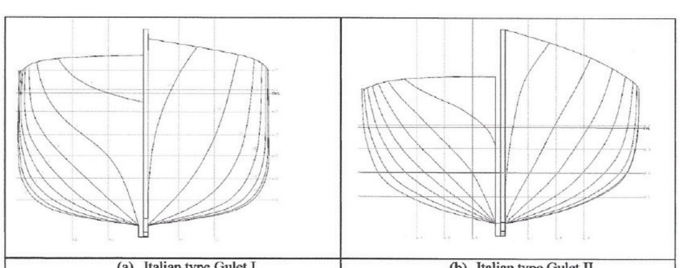

Figure 1. *Hull geometry of Italian type gulets [13]*

There is general rhetoric that gulets come from schooner type boats. The word "gulet" is defined as a variant of the schooner, specific to the Mediterranean [14]. Uskuna type boats of Dutch origin, known as Schooner in English, are known as Goletta in Italian and Goélette in French [15]. It is also known that the word "goulettes", which means sea swallow in French in the 18th century, was used to describe a sailing was ship [1]. Goletta, which is also known as schooner, is a sailing boat type, which has two masts with equal height or a lower foremast [16].

The first schooner type boat was designed and built by Andrew Robinson in Gloucester, Massachusetts, USA, in 1713 to meet the demand for fast sailing boats in the international tea trade [14]. On the other hand, it is widely thought that schooners were originated in the Netherlands. According to Kükner and Kınacı [17], gulets were originated in the Netherlands; then they spread to England and America before arriving in Europe via Italy and France. The schooner is a two-masted medium-sized sailboat equipped with a bow mast, square rig, and mainmast with fore [14,18].

Thus, both gulet and schooner can be identified based on the rigging type considering all the above statements. On the other hand, the term "gulet" has been used in Turkey for defining the body form designed with a round stern or transom stern [19].

Gulets were widely used in the Mediterranean for various purposes. These types of sailing boats started to appear in the Mediterranean in the late 18th century. Until the gulet "Madonna Annunziata", which had a capacity of 92 barrels and was granted a "Venetian license" by the Senate on December 20, 1788, in the Adriatic [20]. Since then, the number of gulets in the Mediterranean increased significantly and spread into many countries. Records stated that 1 gulet was registered in Trieste in 1789, 1 in 1791, and 8 in 1794 [20].

On the other hand, gulets were started in the early 1800s in Ottoman Empire. It is known that gulets were used for military purposes in the Ottoman Navy in the first half of the 19th century [14,21]. According to Tercüman-ı Ahval, an early newspaper released in 1860, gulets were used in coastal transportation and carried commercial goods from Mytilene, Chios, Crete, Bodrum, Tripoli, and Canakkale to İstanbul [14]. Based on the special hull form, gulets had high seakeeping performance even in harsh weather and high-volume capacity, enabling them to be used in the transportation of commercial goods.

Over the years, gulets have started in tourism, along with carrying goods, fishing, and sponging in the Aegean Sea [1,13,17,22]. In Bodrum region, gulet production has started at the end of the 1950s. Mehmet Uyav and Ziya Güvendiren, early boat builders in Bodrum in the years 1958-1959 built two different gulets [23]. Ayaz [24] stated that a 22 m length "karavoskaro" type boat, called "goletta" by Italians, began to be built in 1958, and the masters from Bodrum improved this type of boat over time, revealing Bodrum gulet. These special yachts are now recognized as an essential component of Blue Voyage. As needs and requirements evolve over time, some minor and major modifications have taken place in interior spaces and hull forms of Bodrum gulets. In Blue Voyage, the demand for larger accommodation spaces on the lower deck led to a sub-category of Bodrum gulets, named Bodrum gulets with transom stern.

Even the term "Bodrum gulet" refers to a type of yacht with elliptical stern form, wine-glass shaped midsection, and a concave stem form. In this research, this original unique form will be labeled as "Bodrum gulet with round stern." The most recently revealed sub-category of Bodrum gulet with transom stern is called "Bodrum gulet with transom stern."

1.2. Bodrum Gulets with Round Stern

Generally, Bodrum gulets have two masts: violin-shaped bow and scoop-formed stern [15]. The hull forms of Bodrum gulets have evolved significantly over time due to changes in usage purposes. Figure 2 depicts the lines plan of a modern Bodrum gulet with a round stern.

Having an elliptical stern provides smoother waterlines near the propeller [11]. Therefore, its unique stern form supplies aesthetically satisfactory design and hydrodynamics. However, Bodrum gulets with round stern are not advantageous in aft-lower deck volume compared to Bodrum gulets with a transom stern. Generally, the aft part of lower not suitable for use as a guest cabin, is used for storage, crew area, or galley areas on Bodrum gulets with round stern form.

1.3. Bodrum Gulets With Transom Stern

A special yacht type, which is called transom stern yacht in Bodrum, arose by changing the aft side of Bodrum gulets. This type of boat, which appeared in Bodrum after 1985, is a form used for sailboats in Northern Europe for centuries [15]. Transom stern type yacht is a version of the gulet, created by making a flat mirror shape transom instead of a round stern, resulting in the effort to increase the load-bearing capacity and the search for a large working area [19]. Figure 3 shows the lines plan of a Bodrum gulet with a transom stern.

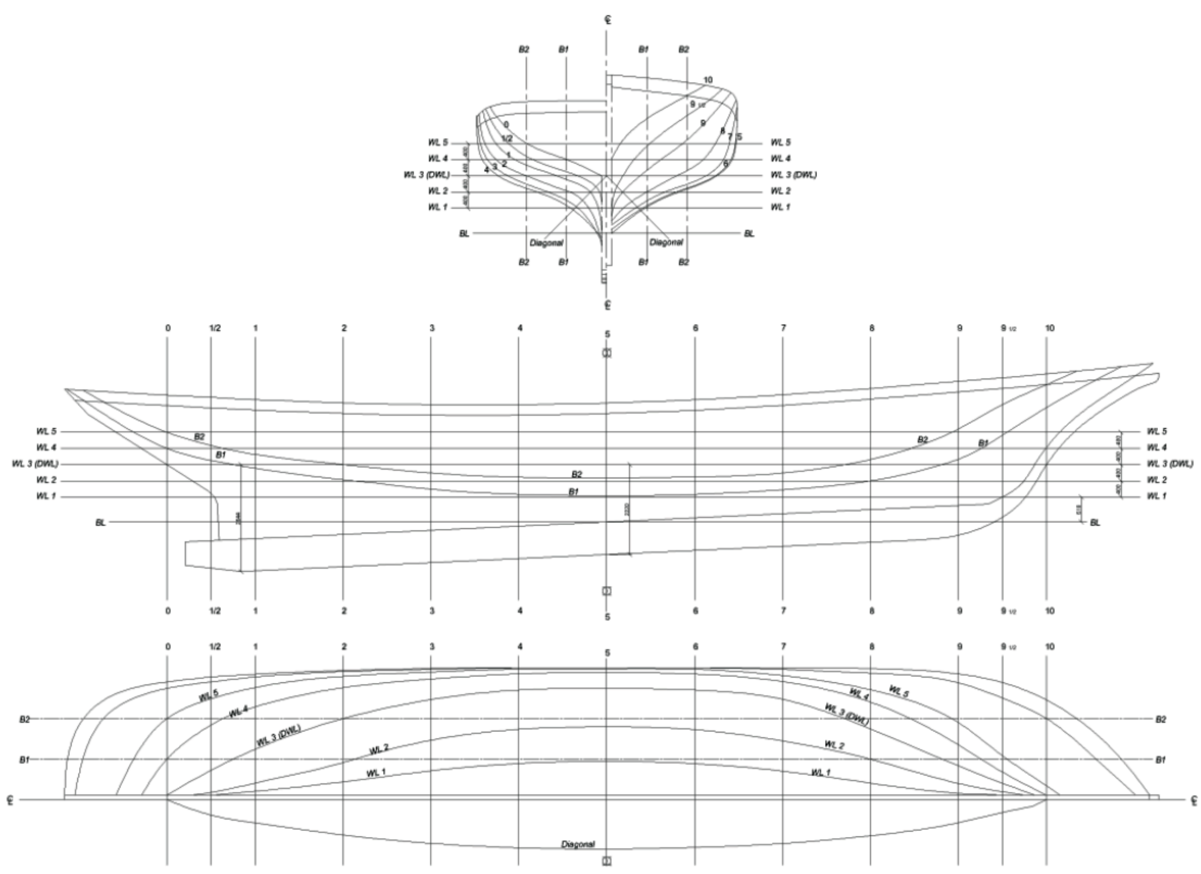

Figure 2. Lines plan of a modern Bodrum gulet with round stern

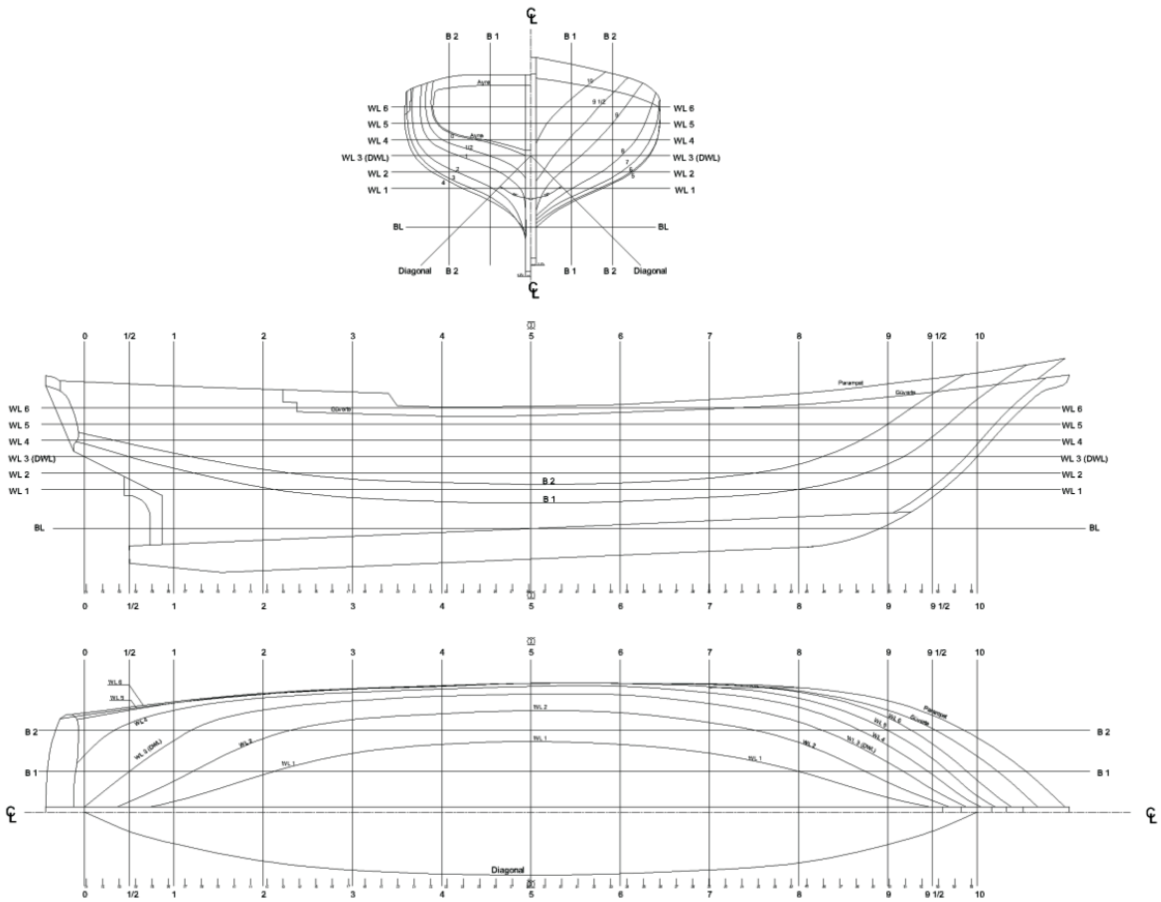

Figure 3. Lines plan of a Bodrum Gulet with transom stern

Except for their aft part of the hull, these yachts with transom stern have a similar hull form as Bodrum gulets with round stern. Transom stern has other advantages such as easier construction and providing additional buoyancy in stern with the possibility of balancing stern trims and disadvantages such as a decrease in propulsion efficiency, increased vibration of the hull, and worse performance in waves when compared to cruiser stern hulls [11]. The main feature that distinguishes the transom stern gulets from the traditional gulets is that the stern sections are not round but rather raised, as in the gulets [25]. On the other hand, transom stern has disadvantages such as increased resistance in low speeds, decreased propulsion efficiency, and high vibration due to clearance limitation between the propeller and the hull [11]. Therefore, a proper guide for the preliminary design phase is required to understand the hydrostatic and geometric parameters of these yachts.

2. Methodology

Twenty Bodrum gulets with round stern and 24 Bodrum gulets with transom stern, built-in Bodrum between 1989 and 2020 and still in service, are selected for analyses. In order to increase the accuracy of results, yacht, which are being used only in Blue Voyage and private use, were selected, and daily trip boats were not considered in this research. Figure 4 presents the steps for the investigation and analysis. In this process, 44 Bodrum gulets are analyzed geometrically, and non-dimensional parameters specific to hulls are obtained for curve fitting. In this step, it is important to keep the correlation coefficient (R-square) for dependent variables as high as possible to obtain reliable results [26]. After geometrical evaluation, hydrodynamic characteristics are investigated, and the resistance of 44

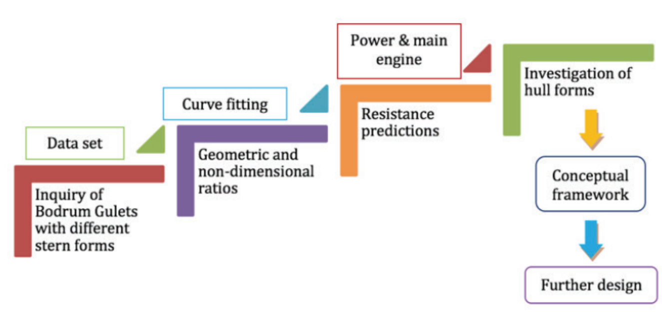

***Figure 4.** Investigation and analysis steps of the preliminary design phase*

gulet forms is calculated using the Holtrop-Mennen method. After getting resistance values, effective and break horse powers are estimated as summarized in the following equations. Within the obtained data, hull forms are evaluated, and a conceptual design framework for Bodrum gulets with round and transom sterns is created using the dominant parameters.

Hulls of yachts were modeled using the Rhinoceros 3D (Ver. 5) program, and the models were imported to Maxsurf software to obtain hydrostatic and geometric parameters. For comparing resistance characteristics of the selected Bodrum gulets, the resistance module of Maxsurf software was used. The Holtrop-Mennen method was used in resistance prediction because it is based on the regression analysis of different scale model tests and trial data and is a useful tool for displacement type hulls [27,28].

According to the mathematical model [29,30] of the Holtrop-Mennen method, the total resistance of a ship can be calculated as follows (formula 1 is below):

$$R_{tot} = R_V + R_W \tag{1}$$

Where R_V refers to the viscous resistance; R_W refers to the wave-making resistance. In other words, the total resistance of a ship consists of friction and residual resistances. The viscous resistance is formulated as follows (formula 2 is below):

$$R_V = (1 + k)R_F \tag{2}$$

Where R_F is frictional resistance according to the ITTC-1957 formula; the form factor k is a function of following parameters [30] (formula 3 is below):

$$k = f\left(\frac{B}{L}, \frac{T}{L}, \frac{L}{L_R}, \frac{L^3}{\nabla}, C_P, c\right) \tag{3}$$

Where L_R is the length of run calculated with statistically derived formulation; c is the coefficient based on the shape of the afterbody which is related with the stern shape coefficient varying with the form types such as V-shaped or U-shaped. The wave resistance is estimated as follows (formula 4 is below):

$$R_W = c_1 c_2 c_3 \nabla \rho g e^{\left(m_1 F_n^d + m_2 \cos\left(\lambda F_n^{-2}\right)\right)} \tag{4}$$

Where c_1, c_2, c_3, m_1, m_2, and λ are the coefficients [29] which are the functions of form; F_n is the Froude number depends on the velocity of the vessel. By using the total resistance, effective power (EHP) can be estimated for Bodrum gulets. Even EHP does not represent the power of the engine at a given speed due to losses in propulsion and interaction of the flow around the hull, providing a starting point for related calculations [31]. It is possible to obtain shaft horse power approximately by multiplying EHP by 2 [32]. The EHP of the vessel can be calculated as follows (formula 5 is below):

$$P_e = R_T V \tag{5}$$

During analysis, 8, 10, and 12 knots are used for the resistance prediction.

3. Results

3.1. Position of Longitudinal Center of Buoyancy and Longitudinal Center of Flotation (in % of L_{WL})

Longitudinal Center of Buoyancy (LCB) is an important parameter used in the weight distribution and consequently in trim calculations in the preliminary design process of a ship. Moreover, this hull form parameter is used in determining wave generation characteristics of the hull. As the LCB shifts to the forepart of the amidship too much, the ship tends to generate more waves in the bow shoulder whereas the LCB shifts to the aft part too much, probability of flow separation and vortices increase [11]. Besides, from the resistance point of view, the LCB/L ratio is a remarkable parameter to estimate the resistance-displacement relationship for a different type hulls [5]. As long as the longitudinal center of gravity does not match with the longitudinal center of buoyancy, a trim occurs on a vessel to match these two points [33]. The minimum, the maximum, and the mean value among the selected yachts' LCB and Longitudinal Center of Flotation (LCF) position in % are shown in Table 1. According to the data, there is a difference in LCF as 1.15%, between Bodrum gulets with round stern and Bodrum gulets with transom stern.

3.2. Hull Form Coefficients

Hull form coefficients are key parameters to determine the hydrostatic and hydrodynamic characteristics of the yachts. Load, resistance, power, maneuvering, and seakeeping performances are related to these coefficients so that in the design phase of a ship, these parameters should be investigated in detail. Moreover, these coefficients also influence the functionality of yachts which have aesthetic concerns and customer-based requirements. Therefore, the designer and/or the engineer has a comprehension of the yacht's hull characteristics such as beaminess, fineness of the hull ends, fullness of the hull, etc. In this section, important dimensionless hull coefficients of Bodrum gulets with two different stern forms are compared and discussed. Table 1 presents hull form coefficients of 20 Bodrum gulets with round stern and 24 Bodrum Gulets with transom stern.

Block coefficient describes the fullness of a hull and a dominant factor on weight and resistance. Decrease in block coefficient (C_B) has positive effects such as improving seakeeping and decreasing required propulsion power whereas it has negative effects such as increasing curvature in sections [34]. The prismatic coefficient is used to determine fullness or fineness of the hull's ends by considering the immersed volume and midship section area [35]. Midship area coefficient (C_M) is used to develop a new design and compare two different boat designs [36]. The waterplane area coefficient is calculated by dividing waterplane area by the multiplication of L_{WL} with beam of waterline (B_{WL}). Its value ranges between 0.6 and 0.8; the higher values indicate the fullness of the yacht's ends [37]. According to the results, there is a significant difference in C_P values calculated as 6.06% for Bodrum gulets with round stern and Bodrum gulets with transom stern (see Table 1).

3.3. Length - Beam Correlations

Length overall (L_{OA})/Length of waterline (L_{WL}) ratio gives an idea about the overhangs of a yacht in the longitudinal direction. Ledges of a modern hull are decreased for fashion-related reasons and to reduce the longitudinal gyradius for an effective waterline Larsson and Eliasson [38]. In Table 1, the minimum, the maximum, and the mean values for round stern and transom stern Bodrum gulet types are shown. The L_{OA}/L_{WL} ratio differs by 5.6% between Bodrum gulets with round stern and Bodrum gulets with transom stern.

Length/beam ratio helps to understand "beaminess" of the boat [39]. Like many other dimensionless ratios, the L_{OA}/B ratio depends on the size of the yacht; it increases as the yacht's length increases because large yachts are less beamy [38]. A beamy boat has the advantages of having a large interior space and high stability in normal angles, but it also has disadvantages of possibly increased difficulty to steer in strong winds and reduced stability in large angles [40]. The studies show that beam and waterline length have significant effect on a boat's wave resistance [41]. Narrowboats are advantageous by providing ease in cruising in waves; however, they are disadvantageous by providing less accommodation in interior spaces and less initial stability when they are compared with beamy boats [40]. Figure 5 depicts L_{OA}/B ratio distribution based on the selected yachts.

As the length of the boat increases, the length/beam ratio's common value shifts from the range of 2.8 and 3.2 to the range of 3.2 and 3.8 [40]. The change of L_{OA}/B ratio is similar for both stern forms, as shown in Figure 5.

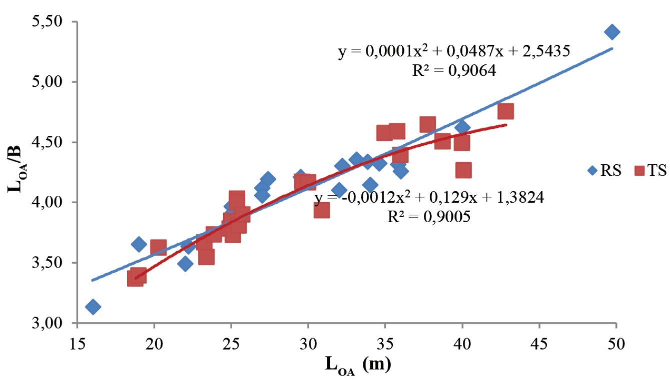

Figure 5. *L_{OA}-L_{OA}/B ratio distribution of gulets with round and transom sterns*

RS: Round stern, TS: Transom stern, L_{OA}: Length overall, B: Beam of the hull

Table 1. *Ratio and values obtained from the research for Bodrum gulet with round stern and transom stern*

Parameters	Round Stern			Transom Stern		
	Min	Mean	Max	Min	Mean	Max
LCB (%L_{WL})	44.49	49.73	62.96	46.95	49.70	54.58
LCF (%L_{WL})	44.64	49.48	63.13	46.02	48.33	54.21
Cb	0.18	0.21	0.30	0.18	0.20	0.22
Cp	0.62	0.66	0.72	0.53	0.62	0.69
Cm	0.30	0.36	0.46	0.32	0.37	0.42
Cwp	0.68	0.73	0.79	0.65	0.71	0.76
L_{OA}/L_{WL}	1.19	1.25	1.32	1.11	1.18	1.27
L_{OA}/B ratio	3.14	4.13	5.42	3.37	4.04	4.75
B/B_{WL} ratio	1.00	1.10	1.20	1.03	1.09	1.21
Disp./length ratio	174.35	205.92	271.84	133.97	190.82	252.83
Keel angle (^{0})	1.80	1.96	2.10	1.78	1.96	2.10

LCB: Longitudinal Center of Buoyancy, LCF: Longitudinal Center of Flotation, Min: Minimum, Max: Maximum

3.4. Displacement/Length Ratio

The displacement of hull in transom stern Bodrum gulets is greater than that of round stern due to an increase in volume of the aft along with the waterline length. Figure 6 depicts the change of displacement with respect to overall length.

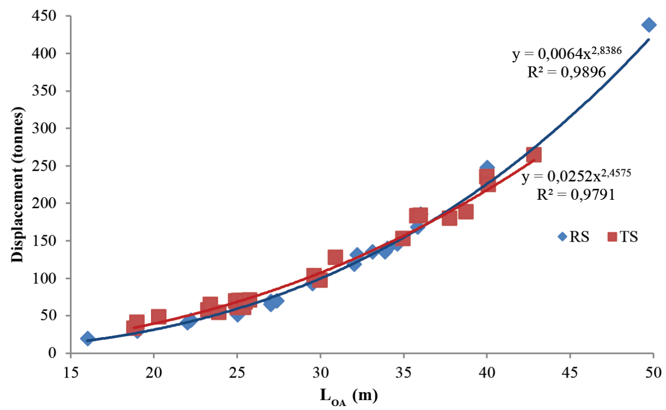

Figure 6. *Displacement distribution of Bodrum gulets with different stern forms*

RS: Round stern, TS: Transom stern, L_{OA}: Length overall

Moreover, the displacement/length ratio is obtained using the weight and cubic waterline length $(0.01xL_{WL})^3$ of the vessel [38,40]. There are five different displacement descriptions for the yachts according to displacement/length ratio; ultralight displacement for the ratio between 50 and 100, light displacement for the ratio between 100 and 200, moderate light displacement for the ratio between 200 and 250, moderate high displacement for the ratio of 250 to 300 and heavy displacement for the ratios of 300 or greater [40]. The low displacement/length ratio represents low wave-making resistance by the hull [4]. There is a significant difference in displacement/length ratios of Bodrum gulets with two different stern shapes, as presented in Table 1.

The overall length of typical Bodrum gulets ranges between 18 m and 25 m; thus, Bodrum gulets with round and transom sterns can be classified in moderate light displacement vessel groups.

3.5. Resistance Characteristics

After calculating the resistance performance of Bodrum gulets with two different stern shapes for three different speeds using the Holtrop-Mennen method, the obtained results were combined in a graph to examine the similarities and differences between these two hull forms. Figure 7 shows resistance values of Bodrum gulets with transom stern and round stern for 8, 10, and 12 knots.

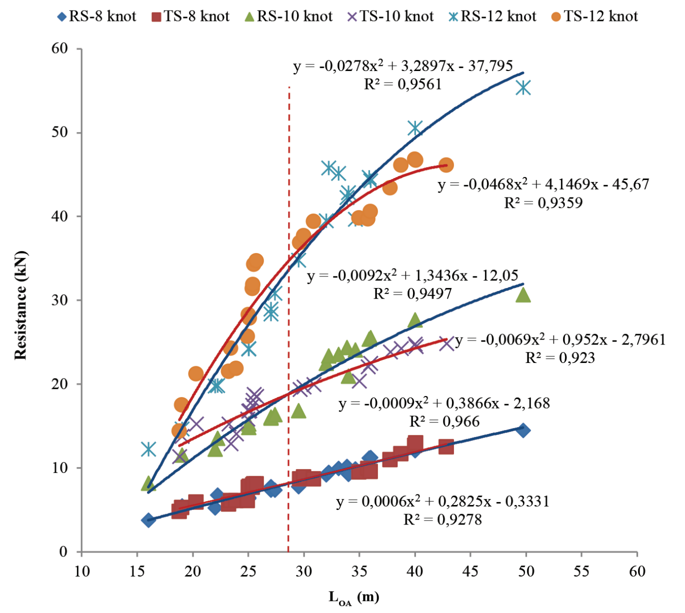

Figure 7. *Change of resistance with respect to L_{OA} and vessel speed*

RS: Round stern, TS: Transom stern, L_{OA}: Length overall

The resistance values of Bodrum gulets with two different stern shapes are similar at 8 knots, as shown in Figure 7. However, compared with transom stern, Bodrum gulets with round stern differ remarkably, especially at 10 knots service speed and at 12 knots maximum speed when the L_{OA} is 28 m or greater. Based on results, Bodrum gulets with transom stern have approximately 15% less resistance compared to Bodrum gulets with round stern at high speeds when the L_{OA} is greater than 28 m. This gap can be explained by differences in C_p and displacement/length ratios, which are the function variables affecting viscous resistance in the Holtrop-Mennen method and differences in flow regime due to stern shapes. According to the resistance results, Froude numbers range between 0.25 and 0.40 at speed ranging from 8 and 12 knots. For typical L_{OA} values, the resistance of transom stern is higher than that of round stern at the same Froude numbers, based on the difference in flow characteristics at sterns. Sharp corners at transom stern result in flow separation that increases drag [11,42]. Furthermore, 28 m represents a critical L_{OA} boundary to be considered in decision making for resistance calculations. L_{OA} values below and above 28 m exhibit significant differences in resistance, particularly at a service speed of 10 knots. Figure 8 presents the estimated engine powers based on the resistance calculations.

The break power of engines installed in typical Bodrum gulets ranges between 280 HP and 450 HP for 12 knots maximum speed, as shown in Figure 8. Similar to the resistance data, the required engine power is higher for

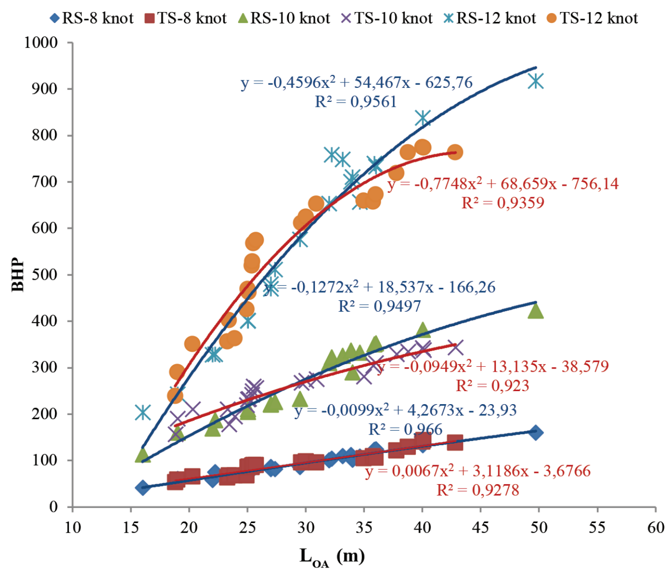

Figure 8. *Change of BHP with respect to L_{OA} and vessel speed*

RS: Round stern, TS: Transom stern, L_{OA}: Length overall, BHP: Break horse power

transom stern than that of round stern below the overall length of 28 m. Consistent with the resistance values, 28 m represents a critical threshold in the preliminary design process when a service speed of 10 knots is taken into account. As the L_{OA} of Bodrum gulets exceeds this critical value, the ones with transom stern tend to be more advantageous in terms of BHP. In contrast, Bodrum gulets with round stern provide the advantage of resistance and BHP for the L_{OA} values lower than 28 m for 10 and 12 knots, the service speed, and the maximum speed.

3.6. Conceptual Framework

A conceptual framework shown in Figure 9 is developed using geometric, hydrostatic, and hydrodynamic data obtained in the previous sections. Using L_{OA}, it is possible to make a preliminary design of Bodrum gulets with round and transom sterns with this framework.

This framework also provides a guideline in which the designer can obtain L_{WL}, B, B_{WL}, displacement, Keel angle, resistance, hull form coefficients [C_B, C_P, C_M, waterplane area coefficient (C_{WP})], location of LCB and LCF, values of a Bodrum gulet. Besides approximate values and ratios for the stated parameters, it is possible to estimate the desired parameter, enabling flexible design.

According to Figure 9, Bodrum gulets with different stern forms have similar characteristics. The most remarkable difference between these two types is seen in the location of LCF (in % of L_{WL}), C_P, displacement/length ratio, and L_{OA}/L_{WL} ratio.

4. Conclusions

Bodrum gulets with different stern forms are analyzed in terms of main dimensions driven parameters to reveal the differences and create a framework that can be used in pre-design stage. The following conclusions are drawn for Bodrum gulets with round stern and with transom stern based on the results obtained:

- There are significant differences in the location of LCF (in % of L_{WL}), C_P, displacement, displacement/length ratio, L_{OA}/L_{WL} ratio, which directly affect the resistance performance.

- Considering typical overall length of Bodrum gulets, the round stern is more efficient in terms of resistance compared to transom stern. However, especially for the L_{OA} greater than 28 m and for the service speeds and above, Bodrum gulets with transom stern are more favorable in terms of resistance.

- The similarities in hull form parameters such as LCB (in % of L_{WL}), C_B, C_{WP}, C_M, L_{OA}/B confirm that the Bodrum gulets with transom stern are derived from Bodrum gulets with round stern, and these two hull forms types come from the same family.

- Transom stern seems favorable based on their voluminous aft form providing additional buoyancy and accommodation space.

- The developed framework simplifies the decision-making process in the early design stages of Bodrum gulets.

As further research, the sail performances of Bodrum gulets with different stern shapes will be compared by applying different sail & rigging types, such as schooner and ketch types rigging. In this context, it will be possible to clarify the effects of different stern shapes on the sail performance of Bodrum gulets. Moreover, this research will provide an optimum sail design framework for the Bodrum gulet hull forms by comparing different rig types on these yachts.

Authorship Contributions

Concept design: B.İ. Turan, M. Akman, Data Collection or Processing: B.İ. Turan, M. Akman, Analysis or Interpretation: B.İ. Turan, M. Akman, Literature Review: B.İ. Turan, M. Akman, Writing, Reviewing and Editing: B.İ. Turan, M. Akman.

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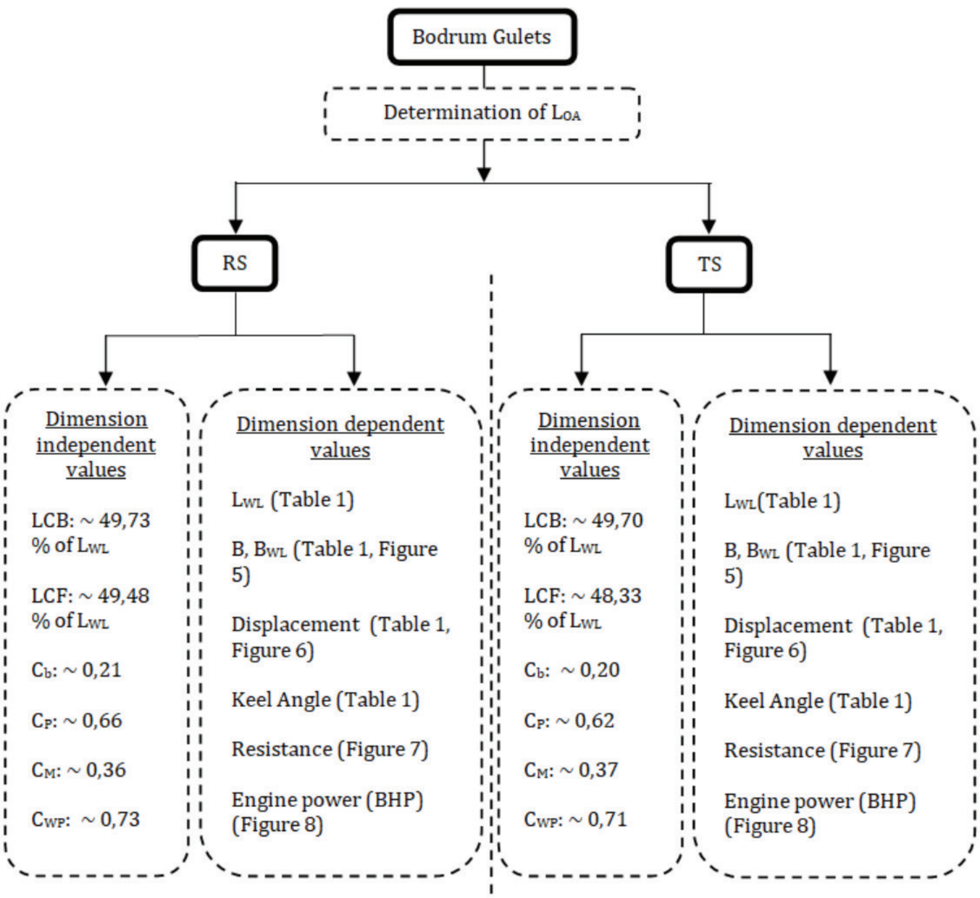

Figure 9. *Preliminary design and engineering framework for hull parameters of Bodrum Gulets with RS and TS*

RS: Round stern, TS: Transom stern, L_{OA}: Length overall, L_{WL}: Length of waterline, LCB: Longitudinal Center of Buoyancy, LCF: Longitudinal Center of Flotation, B_{WL}: Beam of waterline, C_b: Block coefficient, C_M: Midship section coefficient, C_P: Prismatic coefficient, C_{WP}: Waterplane area coefficient

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Risk Assessment for Transporting Ammonium Nitrate-Based Fertilizers with Bulk Carriers

Mehmet Kaptan

Recep Tayyip Erdoğan University, Department of Maritime Transportation and Management Engineering, Rize, Turkey

Abstract

Population growth has enhanced the need for agricultural products. Ammonium nitrate (AN)-based fertilizers are well known to increase product yield. Unfortunately, this type of fertilizer presents serious risks on account of its volatile nature. Accidents continue to occur despite international regulations and practices to eliminate or reduce risks arising from maritime transport to acceptable levels. In the present study, risks related to the transport of AN-based fertilizers were identified through root cause analysis of the M/V Cheshire accident. The relationships between the detected risks and probabilities were quantitatively evaluated using the Bayesian network method, and suggestions to prevent accidents caused by mistakes made during the transport of AN-based fertilizers were provided.

Keywords

Ammonium nitrate, Dangerous good, Hazardous materials transportation, Bayesian network, Risk assessment

1. Introduction

Maritime transport generally features safety and pollution risks due to poor weather and sea conditions, local restrictions, human factors, and variable conditions. Reducing the risks of this type of transport to tolerable levels depends on the introduction and implementation of risk reduction measures. Comprehensive risk assessment is essential for every operation that takes place on board a ship. In this context, the risks of cargo should be evaluated prior to its transport [1-3]. In this study, the risks associated with the transport of ammonium nitrate (AN)-based fertilizers, which greatly impact food production, via bulk carrier were analyzed.

AN-based fertilizers are white crystalline salts produced at low cost from ammonium and nitric acid. These fertilizers are readily soluble in water and used as nitrogen fertilizers in agriculture because they provide a nourishing effect on plant growth [4]. The action time of this type of fertilizer is longer than that of other types of nitrogenous fertilizers [5]. According to a Food and Agriculture Organization of the United Nations report, approximately 153 million of the 243 million tons of fertilizer produced in 2015 is AN-based fertilizer [6]. This type of fertilizer constitutes 2% of all cargo carried by bulk carriers [7]. However, this fertilizer also has high risk of fire, decomposition, and explosion when stocked in large amounts [8]. Details of the physical, chemical, and reactive properties, toxicity, and firefighting and first-aid measures of AN-based fertilizers are available in the literature [9-12]. However AN-based fertilizer accidents continue to occur. Over 70 accidents related to AN fertilizers have occurred in the last century [4]. Indeed, a recent explosion in Beirut linked to AN fertilizers resulted in the death of over 200. Among the fertilizer-related accidents recorded recently, nine occurred during transport on a bulk carrier.

Risk analyses of tankers carrying dangerous liquid cargo [1], passenger ships [13,14], packaged dangerous cargo [15], electrical systems [16], main engines [17,18], and similar fire and explosion accidents are widely available in the literature. Babrauskas [4] examined the incidence of accidents due to AN-based fertilizers and found uncontrollable fires in all reported accidents. Thus, the author stated that the most effective approach to prevent such accidents is the elimination of factors

Address for Correspondence: Mehmet Kaptan, Recep Tayyip Erdoğan University, Maritime Transportation and Management Engineering Department, Rize, Turkey
E-mail: cptmehmetkaptan@hotmail.com
ORCID ID: orcid.org/0000-0003-3304-4061

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causing uncontrolled fires. The author also proposed two suggestions: formulate fertilizers by considering uncontrolled fire risks and build security measures that can address uncontrolled fires. Hadden et al. [19] investigated the fertilizer-related M/V Ostedijk accident, determined the circumstances contributing to the occurrence of fire, assessed the fire response errors, and made appropriate recommendations according to the accident investigation report. Watrobski et al. [20] investigated the problem of sustainable AN transport and found that the current international regulations created to ensure sustainable dangerous cargo transportation are insufficient. The authors used the characteristic object method to select the best scenario for sustainable transport and provided the most ideal transport options considering the factors of safety and transportation costs. Ettouney and El-Rifai [21] analyzed two AN solutions in terms of solubility data, flash point, and boiling point and listed the conditions that could increase the explosion probability of AN fertilizers; these conditions included high solution acidity, accumulation of stainless steel corrosion products, increased temperature, and lack of gas flowing [21].

In the present study, the Bayesian network method is used to analyze fire and explosion accidents caused by the transport of AN fertilizer on a bulk carrier. The rest of this article is organized as follows. Section 2 introduces the Bayesian method used in this study, section 3 describes the methodology, and section 4 provides a comprehensive qualitative and quantitative risk analysis to demonstrate the applicability of the proposed method. Finally, section 5 concludes this study and provides recommendations for future research.

2. Background

2.1. Bayesian Network

Bayesian networks are non-looped graphs used to model the relationships of set elements with an uncertain probability relationship among them [22]. Bayesian networks are probabilistic networks built on the Bayes theorem and enable researchers to make inferences on future incidents by analyzing previous events. Simply put, a Bayesian network is a model that explains the variables of a cluster and the qualitative relationships between these variables in a graphical manner and quantitatively calculates the probabilistic relationships between the same variables [23,24].

Bayesian networks are composed of a graphical component, where the probabilistic relationships between variables are represented by means of nodes and arrows, and the conditional probability tables of the variables. The graphical component forms the structure of the Bayesian network [25]. When two nodes are connected with an arrow, the node at the beginning of the arrow is called the parent node and the node at the end of the arrow is called the child node [26]. Figure 1 shows a Bayesian network consisting of variables A, B, C, D, and E. In this network, nodes A and B are the parent nodes of node C and root nodes. Node C is the parent of node E, and variable D is the child variable of variable B. The conditional probability distributions of the variables $P(A)$, $P(B)$, $P(C|A,B)$, $P(D|B)$, and $P(E|C)$ are indicated in Figure 1. The absence of arrows between a variable in the network and another variable indicates that the variable does not have a probabilistic relationship with other variables in the network; thus, it takes place in the network with a marginal probability (unconditional probability) distribution.

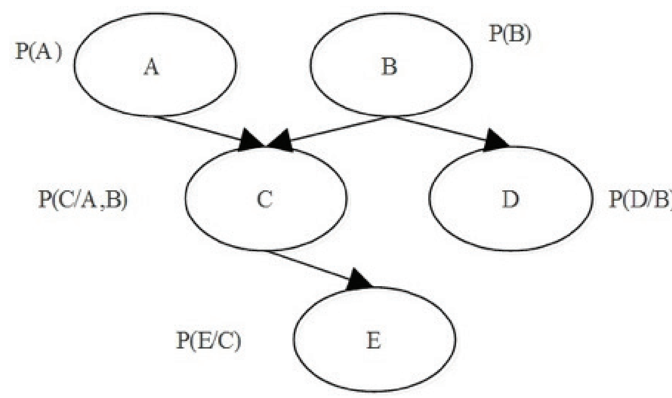

Figure 1. *Example of a Bayesian network structure*

Variables in a Bayesian network are not restricted in terms of the number of children or parents they can have [27] and the use of sub-optimal strategies is essential in domains involving many variables. One approach is the generation of multiple approximate structures and then reduce the ensemble to a representative structure. This can be performed by using the occurrence frequency (on the structures ensemble. If the theory is extended to multiple events, the situations in which a B event can occur together with one of the discrete D events ($D_{1,}$ $D_{2,}$ $D_{3,}$,..., $D_{n,}$) are expressed as in equations 1-2 [26,28,29].

$$P(D_i \mid B) = \frac{P(A_i)\,P(B|A_i)}{P(B)},\ i = 1, 2, 3, 4, \ldots, k \quad (1)$$

$$P(B) = P(D_1)\,P(B|D_1) + P(D_2)\,P(B|D_2) + \ldots + P(D_X)\,P(B|D_X) = \sum_{j=1}^{X} P(D_j) \cdot P(B \mid D_j) \quad (2)$$

3. Methodology

This section introduces the Bayesian network constructed to analyze fire and explosion accidents caused by AN-based fertilizers transported in bulk carriers. Figure 2 shows the flowchart of the proposed methodology. The main steps of the methodology are briefly described below.

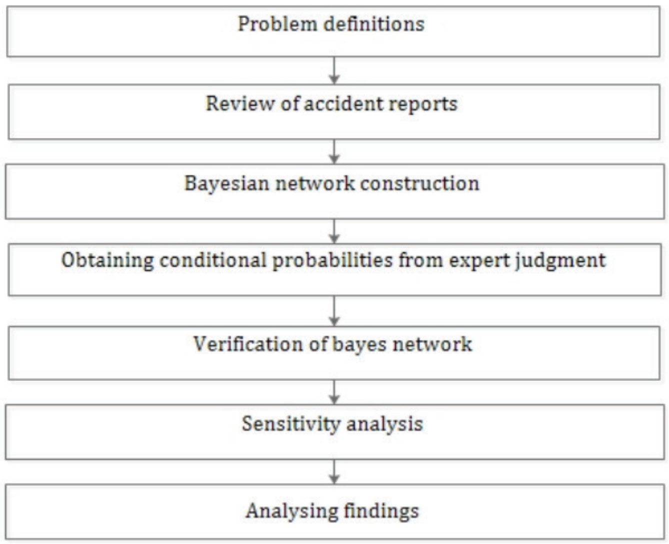

Figure 2. *Flowchart of the study*

3.1. Definition of the Problem

The purpose of this section is to determine the causes of accidents and their occurrence conditions. The necessary data are first collected to reveal the variables causing accidents. Data can be obtained by different methods, as stated in previous studies [30-32]. For example, accident reports or databases may be studied. Surveys or in-depth interviews with subject matter experts may also be conducted. Applying one or a combination of these methods may reveal all factors (variables) causing an accident and the relationships between these factors.

3.2. Bayesian Network Construction

Two methods, namely, expert opinion and data set learning, are used to create the graphical structure of the Bayesian network. Analysis of the graphical structure of the Bayesian network on the basis of expert opinion is not only probabilistic but also causal and explanatory. Moreover, analysis of the network on the basis of data set learning can ensure an objective network structure because the relationships between variables are established via numerical and statistical methods [33]. A graphical network structure showing the relationships between variables is created by one of these data sets. The nodes created in the network structure are also introduced in this stage.

3.3. Conditional Probabilities from Expert Judgment

The conditional probabilities of the nodes can be obtained from expert opinion and data set learning, as stated in the previous sections. If a data set that allows the calculation of node conditional probabilities is not found in the study, it is a practical solution to obtain because of expert evaluation. Experts provide their opinion of each probability in the conditional probability tables of the nodes. Because the opinion of each expert participating in the study does not have the same weight, a weighted score is assigned to these experts. Suppose expert *i*'s decision is represented by x_i. The following equation 3 is used to find the combined measure of expert judgments, x [34].

$$x = \omega_1 \times x_1 + \omega_2 \times x_2 + \omega_3 \times x_3 + \omega_4 \times x_4 + \omega_5 \times x_5 \quad (3)$$

$$= \sum_{i=1}^{5} W_i X_i$$

Each ω_i (i = 1,2,...,5) normalized expert's weight is expressed as $\sum_{i=1}^{5} \omega_i = 1$.

The background and assigned weights of the five experts who participated in this study are briefly explained below.

Expert 1; worked as a captain on bulk carriers for approximately 7 years. Today, he is an academician who completed his Ph.D. on shipping risks. The weight value assigned to this expert is 3 (range, 1-5).

Expert 2; is an oceangoing masteral student with a total of 25 years of service on bulk carriers. Because this expert has loading experience on AN-based fertilizers, the weight value assigned to this expert is 4.

Expert 3; works as a chemistry professor at a university and has published several SCi articles on inorganic chemistry. Therefore, the weight value assigned to this expert is 5.

Expert 4; has worked as a chemist for 10 years in the laboratory of a factory that produces AN-based fertilizers. The weight value assigned to expert is 1.

Expert 5; is an oceangoing master with a total of 25 years of service on bulk carriers. Thus, the weight assigned to this expert is 2.

3.4. Verification of the Bayes Network

Axioms tests are used to confirm that the Bayesian network is built correctly and working as designed [34]. Requests for axiom tests must be met by the Bayesian network for the latter to be considered valid. Tests of the following axioms were applied to the Bayes network established in this study. Axiom 1: The change in probability of each parent node would cause a relative change in the probability of the child node. Axiom 2: Considering the probability distributions of each parent node, their impact on the child node values should be consistent. Axiom 3: The combined effects of a child node with more than one parent node on the probability values of the parent nodes are always greater than the individual effects [35].

3.5. Sensitivity Analysis

Sensitivity analysis determines whether any variable (node) in the network is sensitive to the difference in the status of any other variable in the network [36,37]. Sensitivity analysis results are usually represented as deviation values. Deviation values are defined as an expected decrease/increase in the selected output variable depending on the value of the input variable [38]. The input variable, which is determined to have the highest variance reduction value due to the analysis made on this variable, is expected to shift the probabilities for the conditions of the target variable toward the maximum value. In other words, how changes in the inputs (i.e., root node, parent node) of the Bayesian network will affect the output (i.e., child node) is calculated in the network. In this study, the outputs of the network are the probability of explosion accidents caused by AN-based fertilizers. The inputs are defects that play a role in the occurrence of the accident. The GeNIe software package was used for the axiom tests and sensitivity analysis [39].

4. Application

The proposed methodology was applied to an actual maritime accident; specifically, the M/V Cheshire accident was selected to conduct a comprehensive risk analysis. The M/V Cheshire bulk carrier sailed from its loading port in Norway on 6 August 2017 to Thailand with a load of AN-based fertilizers. A bad odor and dust, pressure, and water accumulation were observed when the hatch cover drains were opened 3 days into the voyage. The ensuing accident resulted in the complete loss of the ship because these signs and the accompanying increase in hatch temperature were not interpreted correctly by the ship's personnel; thus, intervention was delayed [40].

4.1. Establishing the Bayesian Network Structure

The causes of the accident and the relationships between these causes were determined on the basis of the M/V Cheshire accident. Thus, a tentative network structure was formed. The final form of the network structure was decided by considering the experts' opinions on the network structure. The Bayesian network in this study consists of 11 nodes in total (Figure 3). Information about these nodes is given below.

Cargo Declaration

According to SOLAS Chapter VI rules 1 and 2, the shipper is obliged to inform the captain about the cargo before loading, as specified in International Maritime Solid Bulk Cargoes (IMSBC) code rule 4. The cargo must be packed properly and transported safely. This node considers causes of inappropriate reports.

Heat Source

A heat source is necessary to initiate the decomposition of AN-based fertilizers. Thus, operations involving welding, burning, or cutting and equipment that could generate fire, open flames, or sparks should not be performed near the cargo hold containing this cargo, except for emergencies. This node considers improper practices performed by the ship's crew.

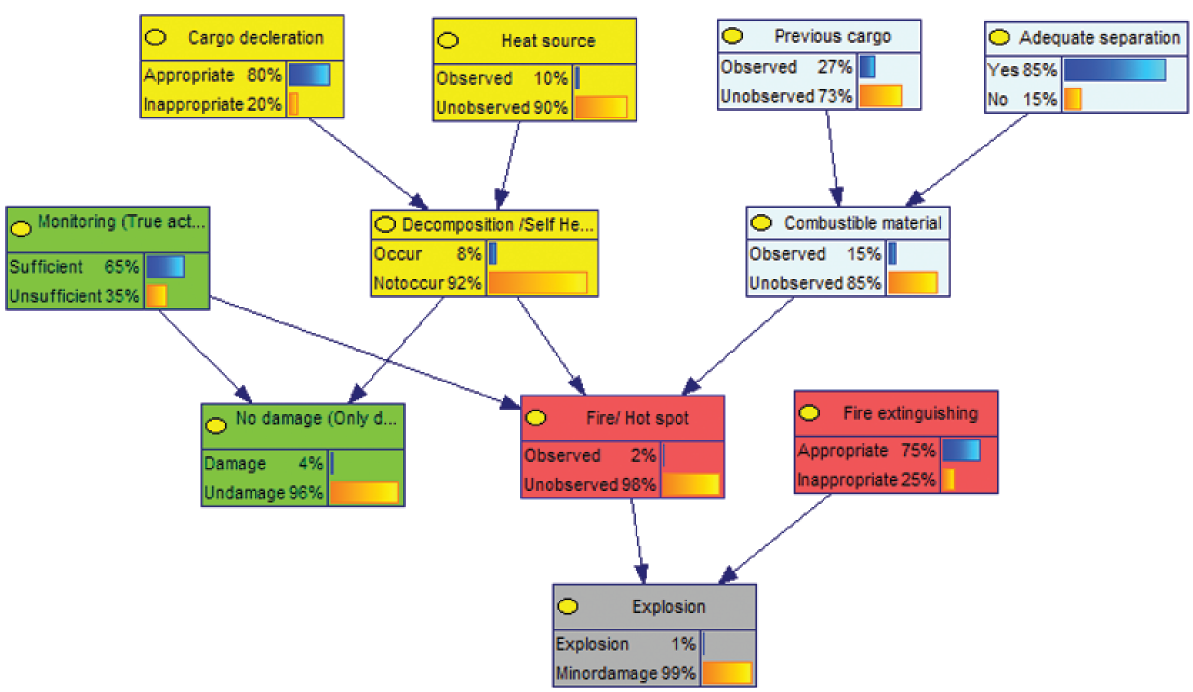

Figure 3. *Bayesian network structure for Ammonium nitrate (AN)-based fertilizer-induced explosion*

Previous Cargo

Cargo holds in which AN-based fertilizers are to be loaded should be washed with salt and fresh water and free of previous load residues. This node considers improper practices of seafarers.

Adequate Separation

The compatibility of AN-based fertilizers with other cargo loaded in the same cargo hold should be considered prior to loading. Bulk carriers must be arranged, equipped, or approved to transport AN-based fertilizers in their hold. This node considers non-conformities to established practices and requirements

Monitoring (True action)

AN-based fertilizer decomposition shows observable and measurable signs, including a decrease in the atmospheric oxygen content of the cargo hold, water accumulation in the hatch cover channels, effluvium, temperature increases, and fume formation. This node considers the crew's misunderstanding of the signs observed and improper actions.

Decomposition

AN-based fertilizers can be chemically decomposed upon exposure to heat. This node considers the probability of decomposition occurring.

Combustible Material

AN does not burn, but it is an oxidizing agent and, therefore, can support combustion [8]. The presence of flammable materials is necessary to produce a fire involving AN. This node considers the inconveniences caused by the combination of AN-based fertilizer and flammable materials.

No Damage (Only dusk)

This node considers the level of damage sustained by the ship following appropriate action by the ship's personnel when the separation of AN-based fertilizers begins.

Fire/Hot Spot

This node reflects the possibility of fire caused by a fertilizer based on AN.

Fire Extinguishing

A suitable extinguishing medium for AN-based fires is water. The use of other extinguishing materials (e.g., foam, carbon dioxide) is useless in firefighting this type of fire and even encourages decomposition. This node considers the operational errors made within the ship.

Explosion

AN-based fertilizers can explode under certain conditions that require a strong start-up source. This node considers the possibility of explosion.

4.2. Axiom Test

The axiom 1 test was implemented over the entire Bayesian network constructed in this study, and a sample application was carried out using the Fire/Hot spot node. Parent nodes affecting the formation of this node include the monitoring (true action), decomposition, and combustible material nodes. When the individual negative statements of the parent nodes of the Fire/Hot spot node are 100%, the probabilities of Fire/Hot spot formation are 3%, 22%, and 5%, respectively (Table 1). This result confirms that an increase in the probability of each parent node causes an increase in the probability of the child node; conversely, a decrease in the probability of each parent node causes a decrease in the probability of the child node. All of the results obtained show that the Bayesian network fulfills the test requirements of axiom 1. Thus, the Bayesian network created is compatible with the axiom 1 test.

Table 1. *Results of the Fire/Hot spot node-based axiom 1 test*

Triggering factor for Fire/Hot spot	Fire/Hot spot
Monitoring (True action)	Observed (%)
35%	2%
100%	3%
0%	1%
Decomposition	Observed (%)
8%	2%
100%	22%
0%	0%
Combustible material	Observed (%)
15%	2%
100%	5%
0%	1%

The axiom 2 test was conducted on the Fire/Hot spot node; here, a gradual increase in the parent nodes independently for example,10%, 20%, 30%....100%) caused the probability of the child node to increase gradually. This finding indicates that a gradual change in the probability distribution of the parent nodes exerts a consistent effect on the child node. Thus, the Bayesian network complies with axiom 2 requirements.

According to the axiom 3 test, when 100% independent negative probabilities of the parental nodes of the Fire/Hot spot node are selected, the probability values for the "observed" state of the Fire/Hot spot node are 3%, 22%, and 5%, respectively. When these three parent nodes are given 100% negative probabilities, the probability value (observed) of the Fire/Hot spot node is 100%. The results obtained are consistent with the axiom 3 test. The axiom 3 test was also applied to all intermediate nodes, and results consistently indicated that the Bayesian network fulfills axiom 3 requirements.

4.3. Sensitivity Analysis

In the sensitivity analysis, the probability of the Explosion node was changed to 0% and then 100% by using the GeNIe program. No change was made to the probabilities of other nodes in the network. The change in the probability values of the nodes was then examined, and the effects of the causes (nodes) of explosion accidents due to AN fertilizer on the occurrence of these accidents were quantitatively calculated using the Bayesian network created in this study. Table 2 shows the sensitivity analysis results.

5. Results and Discussion

The Bayesian networks created in this study demonstrate the factors causing the explosion of AN fertilizers and the relationships among these factors. Users of the network can understand the occurrence of AN fertilizer explosion and predict the risk of explosion when several factors are present in the environment. Nodes that stand out according to the results of the explosion sensitivity analysis include heat source (93%), combustible material (32%), Fire extinguishing (25%), and monitoring (true action) (17%) (Table 2).

Table 2. *Sensitivity analysis results of AN-based fertilizer-induced explosions*

Factor affecting explosion	Negative conditions	Probability of AN explosion (%)		
Node		0 (%)	100 (%)	Effect (differences)
Cargo declaration	Inappropriate	20	27	7
Heat source	Observed	9	100	93
Previous cargo	Observed	27	47	20
Adequate separation	No	15	26	11
Monitoring (true action)	Insufficient	35	52	17
Decomposition	Occur	7	100	95
Combustible material	Observed	15	47	32
Fire/Hot spot	Observed	1	100	99
Fire extinguishing	Inappropriate	75	50	25
Cargo declaration	Inappropriate	20	27	7
Heat source	Observed	9	100	93
Previous cargo	Observed	27	47	20

AN: Ammonium nitrate

The root cause of explosion accidents was determined to be heat source. Decomposition of AN-based fertilizers may occur via two ways: Thermal decomposition and self-sustaining decomposition (SSD). In the case of thermal decomposition, removing the heat source from the environment may be sufficient to prohibit further decomposition. However, even if the heat source causing thermal decomposition is removed, sufficient heat may remain in the material because of chemical reactions, which give rise to SSD [10]. In this case, the size of the heat source to which the cargo is exposed, the exposure time of the cargo, and the tendency of the cargo to under SSD must be assessed [41]. The decomposition tendency of the load is determined by the trough test specified in the IMSBC code. The risk of cargo degradation is significant at temperatures exceeding 170 °C [8]. Thus, internal heat sources (welding, naked flame, electrical equipment etc.) must be kept away from the cargo. The temperature inside the hold may also increase due to the heat of the area in which the ship is located. The importance of heat sources has been emphasized in previous studies [2,21].

Besides keeping heat sources away from the cargo, strict observation of the condition of the cargo may be an effective approach to avoid explosion accidents. Accident investigation reports often reveal a lack of understanding of the signs of decomposition during the transport of cargo, as well as incorrect action due to the lack of information. When accidents in vessels such as the M/V Purple Beach and M/V Cheshire were examined, strain due to pressure, effluvium, and water accumulation were observed when the hatch cover drains were opened within the first days of sailing. However, these signs were ignored by the ship's crew. Subsequent interventions were thus insufficient, and the ensuing accidents resulted in the complete loss of the ships [40,42]. Given these reports, all crew members must have detailed information on the need for hold cleanliness, cargo hazards, stowage and segregation, loading, weather, carriage precautions, and discharge on ships carrying AN-based fertilizers.

Another important factor in the formation of AN-based fires and explosions is material combustion. AN-based fertilizers are not combustible but are self-oxidizing [43], which could promote combustion. Fertilizers are very sensitive to the residues of flammable materials, such as coal, grain, sawdust, and petroleum [44].Therefore, personnel should remove cargo residues and prepare appropriate stowage plans. Structural equipment, such as hatch covers and bulkheads, should meets the standard requirements of the ship. Baalisampang et al. [45] indicated that detailed risk assessment should be performed to minimize human and organizational errors.

The last node within the scope of this study is the fire extinguishing node. Fire extinguishers suitable for the burning cargo must be available to address fires. The appropriate firefighting methods are listed in the sources as follows. If the deterioration area is small and easily accessible, it can be removed from the main body by using a digging shovel; local extinguishing with water can then be performed. However, if the deterioration area cannot be removed, the area should be sprayed with water by using a high-pressure jet as quickly as possible. Other firefighting methods, such as spraying with foam and carbon dioxide or covering the area with non-combustible materials, are useless and may even encourage decomposition. The amount of water used to stop decomposition should not disturb the stability of the ship [46,47].

6. Conclusion

The development of agriculture and increasing demands for mineral fertilizers have caused the transport of AN-based fertilizers to intensify. Sea transport is prominent in the shipping of this type of fertilizer because this mode of transport is inexpensive. Several factors should be considered when transporting AN-based fertilizers because of their inherent and ship-related risks. The network obtained in this study contributes to the literature by providing a means to predict the probability of fire and explosion accidents caused by AN-based fertilizers. Some recommendations to prevent such accidents are as follows.

- Risk assessment procedures should be developed to identify and eliminate heat sources that may cause decomposition.
- A standard operating procedure that allows communication between the captain and fertilizer specialist during the ship's voyage should be established.
- A monitoring logbook that could track the signs of decomposition, such as odor, dust, and water accumulation, should be prepared.
- SSD may be inhibited by delivering water to the reaction zone. Thus, the availability of three different fog lances on ships carrying AN-based fertilizers as cargo, depending on the height of the ships' holds, should be made mandatory.

Future researchers may focus on the effects of human error on fertilizer-related accidents. Further studies estimating the probability of human error are recommended to provide decision-making support to operational stakeholders.

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ORIGINAL RESEARCH (AR)

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Determining the Level of Institutionalization in Family-Owned Shipping Businesses

Kadriye Oya Turhaner[1,2], Selçuk Nas[3]

[1]Dokuz Eylül University, Graduate School of Social Science, İzmir, Turkey
[2]Yaşar University, Vocational School, Tourism and Hotel Management Program, İzmir, Turkey
[3]Dokuz Eylül University, Maritime Faculty, Department of Maritime Education, İzmir, Turkey

Abstract

The levels of institutionalization have varied in organizations affecting their success and sustainability in business. The objective of this study is to develop a model for determining the level of institutionalization in which family-owned organizations operate the Level of Institutionalization for Organizations (LIFO) by a collaborative social research. This research contributes to the institutional theory by developing a model for an innovative approach to harmonize family and business at the institutional level with 68 variables derived from institutional theory. It also contributes to family businesses in maritime transportation as the LIFO model was used to determine the institutionalization level of shipowners in general as family-owned businesses. The model is based on the variables in both new and old institutional theory. A semi-constructed questionnaire was conducted among 64 out of a total of 244 of shipping companies registered within the country that operate globally. The data is collected through face to face interviews carried out with the heads of family-owned businesses. The data is used for qualitative content analysis. The results reveal the establishments of these organizations were set on firm bases in the pre-institutionalization level; there were fluctuations in doing business and differing attitutes among organizations in the same field in the semi-institutionalization level; there are bigger issues in the sustainability and insitutionalisation of family in the level of full-institutionalization.

Keywords

Institutional theory, The level of institutionalization, The LIFO model, Maritime Organizations, Family-Owned Businesses, Turkish Shipping Business

1. Introduction

"Institutions" can broadly be defined as "structures" that are established. The means of establishment of these structures seems to have varied throughout history. Based on the particular means implemented, the forms and levels of institutions have changed as well. Greenwood et al. [1] categorizes the levels that emerged and gradually developed into four classes namely, "individual", "organization", "field" and "society." According to this categorization, the "individual" level involves the handshake in western societies. The "organization" level entails the use of formal accounting controls while the "field" level comprises of hierarchies of status. Lastly, the "society" level appears as a legal system based upon due process.

Berger and Luckmann [2] point out that the founder's habits are the initial basis for organizational institutionalization. When these habits are shared with the second person in the organization, they form traditions. When the traditions are transferred to third parties participating in the organization, they become sacred orders. Berger and Luckmann [2] also explain that institutionalization is applicable to families as well, wherein spouses with individual habits establish their marriages to create their own traditions which are transferred to their offspring.

Institutionalization is a process in which an organization becomes an institution by social pressures [2]. According to Stewart [3] family businesses are defined as institutions

Address for Correspondence: Kadriye Oya Turhaner, Yaşar Universtiy, Vocational School, Tourism and Hotel Management Program; Dokuz Eylül University, Graduate School of Social Science, İzmir, Turkey
E-mail: oya.turhaner@yasar.edu.tr
ORCID ID: orcid.org/0000-0002-4728-1909

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that act under the influence of a family's emotional system, ownership system and business system. In these institutions, there is also the issue of the family members' emotional commitment. The business has to be kept under the managerial control.

In family businesses, the structures of family relations shape the business structures. Business-owning families have unique "psychological, behavioral, social, and cognitive" [4] aspects that drive idiosyncratic strategic decisions in the firms they own and operate [5]. Family-owned businesses demonstrate the prevailing corporate model in the world, with a significant impact on the emerging economies and developed nations [6]. Family businesses are of great importance for the global economy. According to the Pricewaterhouse-Coopers Family Business Survey held for 2007-2008, the proportion of registered businesses that are family firms is between 50 and 65% in European Union countries, 90% in Latin America, and 95% in the U.S.A. It is also stated in the survey that these family businesses contribute up to 82% of the gross national product in Asia, 45% in North America, 70% in Latin America, and 65% in European Union member states. A more recent study carried out by Bain (2019) on Family Capital shows that by the end of 2018, the family businesses ranked among the top 750 family businesses in the world generated annual revenues of more than $9 trillion USD, and employed nearly 30 million people [7].

As family businesses dominate the world economy, there must be something unique in them as institutions. Perhaps, it is up to the leader as Selznick [8] states when he writes that the leader of an institution is supposed to define its mission to protect its distinctive character. According to Özen [9], institutionalization is a structure that supports the interest of the empowered to become more solid. Institutional context is shaped by organizations. Some powerful organizations attempt to put their own goals forward and apply their procedures directly into the society as if they are institutional rules of the society at large [10].

As the founders come from different customs as individuals, the institutionalized forms of family-owned businesses greatly differ from one another. Yet they are subject to isomorphism by compelling uniformity resulting from political influence and legitimacy problems, by mimetic responses to environmental uncertainty and by normative uniformity resulting from professionalization. So, organizations start to resemble each other [11].

There are many similarities among family businesses. However, it is not always clear whether there is awareness of institutionalization in these businesses, and whether there are levels in their institutionalization. If so, how can the level of this institutionalization be determined? These questions are considered worth pursuing as there are gaps in the relevant literature on such issues. Therefore, collaborative social research was carried out to develop a model that uses institutional theory as its the theoretical perspective.

The objective of this study is to develop a model for determining the level of institutionalization at which family-owned organizations operate the Level of Institutionalization for Organizations (LIFO) by a collaborative social research. For the purpose of this collaborative social research, the principles of institutional theory were gathered and discussed on how to develop a model for determining the level of institutionalization in family-owned businesses.

The first contribution of this study is that it develops a reliable and applicable model that can be used to assess the level of institutionalization in family-owned businesses. The second contribution is that it provides ship-owners with a guideline to determine their level of institutionalization through regulatory and preventive actions. In implementing this model, family-owned businesses in maritime transportation were preferred since maritime transportation is a dynamic global industry. In the international shipping business and the related activities, focus on commercial, economic, operational and legal subjects is required. Therefore, the success of an organization in the maritime industry depends on the skills and knowledge of its founders and employees [12].

Turkish ship-owners were favored in the study. Sea trade and commercial sea transportation commenced in Turkish maritime at the end of the 19th century. Before that, the sea was the battle ground of the Ottoman Empire [13]. The rule of the Ottoman Empire weakened in the late 1800s and following its collapse and Turkey emerged as its successor in 1923. Turkish ship-owners achieved success and became the 15th biggest fleet in size International Labor Organization in 2016, and maintained the same level up to 2020 according to the Turkish Ministry of Transport and Infrastructure. However, between the 1800s and the 1940s more than a hundred family businesses in the maritime transportation industry became defunct [14]. The third contribution of this study is that it assesses the level of institutionalization of Turkish ship-owners to enhance their self-awareness against obstacles and extinction for sustainability.

The literature reviewed, the model developed and the method of the research, the field of the research the population and sample, the data collection and the methods of analyzing the data are presented together with the findings and discussions. The conclusion, the limitations in the research and the suggestions for further researches are also discussed.

2. Literature Review

Leaptrott [15] explains that institutional theory is not a traditional descriptive approach for examining family businesses to identify their structure and symbolic aspects, but for examining them to understand the relationship of interactive forces between overlapping institutions of the family, business, and ownership, as well as considering many external influences.

Institutional theory goes back to the 1800s, to the emergence of sociology. The main areas of interest of this theory are theology and government policies at the beginning of an institution's life. Later, organizations were the focus of studies based on micro-corporate values such as rules and procedures, elites, power and leadership, bureaucratization, organization, informal and formal structures, values, norms and attitudes, and formalization. By the 1970s, the theory had moved to a macro level. The central components are corporate policies and the relationship between organizations and the environment, social, culture, structure, effectiveness and continuity, isomorphism, legitimacy, and relations with employees. The theory is divided into "old institutionalization theory" and "new institutionalization theory".

Berger and Luckmann [2] explain that institutionalization is based on business founders: They have their own habits of doing business. Riley [16] states that individuals take beliefs already set in the community without thinking or conducting research. Hinings and Tolbert [17] contributes that the ethics and thoughts of society are formed by the level of economy achieved.

When the habits of business founders are transferred to the second person in the organization, the organization develops its own traditions [2]. Tolbert and Zucker [18] refer to this step in the institutionalization process as objectification. Özen [9] points out that organizations in the same field are limited to the knowledge and resources available at their time of establishment, and resemble each other in reflecting the conditions of that period.

When business grows, the organization expands. Traditions will be dictated to others joining the organization as sacred orders [2]. Tolbert and Zucker [18] call this step sedimentation. Weber [19] states that between elites who have power and authority and employees who obey the elites, there should be a system working bureaucratically like the gears of a machine. Özen [9] asserts that reliability in bureaucracy requires obedience to rules. Selznick [8] explains that social pressure is required for organizations to become institutions such as families or states. However, employees apply their ways of doing business instead of professional practice while those involved in constituting rules attempt to follow the rules with little deviation [2].

Institutionalization is a process in which various social processes, responsibilities, or realities are shifted to a situation in which social thoughts and behaviors transform into a rule-like status [10]. Selznick [20] suggests that when organizations grow, adaptation becomes difficult, so does institutionalization. The level of difficulty in giving up an organization or activity indicates the level of institutionalization of the organization or business [20].

Socialization in the internal environment, informal structures, interests, and personalities of employees are the other aspects of institutionalization [21]. Corporate leadership is solely the creation and maintenance of values. The organizational leader's identity needs to be established, and the leader must evaluate himself or herself as a servant of the organization [2]. The institutionalization of family business requires both the institutionalization of business and of family [22].

The family council is a tool for family institutionalization and sustainability. It is for improving communication and relationships in the family and for determining the conditions of utilization of the family opportunities [22]. In the council with the members of the family and professionals, young members of the family become acquainted with the necessities of the business [23].

Expanding family with in-laws and cousins and the option of delegating business management and leadership to upcoming generations and heirs requires planning [23]. The constitution of the family focuses on this planning as a part of family institutionalization and its sustainability [24].

The relationship with the external environment is a part of institutionalization. The uncertainty of concern for effectiveness on daily work in institutionalized organizations creates considerable stress. Organizations and their leaders may be urged to choose between the results of their technical activities, efficiency, and the legitimacy of the institutional structure [10].

For the benefit of leaders in family businesses, this study aims to provide a model to determine the level of institutionalization with preventive and regulatory actions to overcome problems in their institutions and achieve sustainability for upcoming generations.

3. The Model and Research Method

In institutional theory, institutionalization is a process initiated in three stages called habitualization, externalization and internalization [2]. During institutionalization, there is repetition of human knowledge, a process referred to as habitualization [14]. The founders of family businesses have naturally unique knowledge and knowledge acquired from doing business. They act similarly in comparable situations with the expectation of economic gain. Yet they are under the influence of technological change and changes in legislation and market forces [18]. All these changes in the environment produce innovations in their habits. Newly altered habits form new traditions in business conduct. These newly set traditions result in renewed sacred orders provided to the members of organizations. The process of institutionalization is thus endless. The study of Berger and Luckmann [2], also describes the process of institutionalization in terms of the three stages defined as habitualization, objectification and sedimentation. Following any innovation, these stages are also the indicators of the level of institutionalization defined as pre, semi and full institutionalization [18].

3.1. The Model of the Research

A model developed for the purpose of this study was based on the research gap in understanding what institutionalization means for family-owned businesses; whether it has a crucial value in their transactions, if there are institutionalization levels and if so, how to determine the level of institutionalization of any family business. Guided by these questions, the model is based both on the studies of Berger and Luckmann [2] and Tolbert and Zucker [18] which identify three institutionalization levels and 68 variables from old and new institutional theories.

In the development of the model for the pre-institutionalization level, it is accepted that family businesses are set up by individual founders. In general, there is a follower, either as the very first employee or as the founders' sons. The habits of founders and traditions gathered in the business with the very first employees constitute the starting point of business and their ways of dealing with business interactions. The pre-institutionalization level is compatible with the emergence and development of family businesses.

As part of the development of the model for the semi-institutionalization level, it is also accepted that as time passes, the numbers of family members working in the family businesses increase, and as the volumes of family businesses expand, so does the number of employees and professionals. Thereby business traditions are passed on as sacred orders to the employees and professionals. The semi-institutionalization level is considered to be the keystone institutionalization process in the development of general and shared social meanings attached to behaviors in business dealings. It is a development that is necessary for enlarging business horizons by expanding actions to contexts beyond their origin. The variables for the semi-institutionalization level were drawn from work by scholars on institutional theory.

For the full institutionalization level, it is accepted that traditions and sacred orders need to pass onto the next generations as families grow larger by marriage and births. The variables for the full institutionalization level were drawn from work by scholars on institutional theory and from family business management.

Based on the acceptance of the three levels for the model, 37 variables from previous studies on old and new institutional theory are clustered as shown at Table 1.

Based on these variables, 68 determinants of the model are developed and clustered for the LIFO model as pre-institutional level, semi- institutionalization level and full-institutionalization level as indicated in Figure 1.

As the research gap is related to family-owned businesses, this study is limited to ship-owning family businesses. For the purpose of this study, empirical research is carried out on Turkish ship-owners. Therefore, the model is titled the Level of institutionalization for organizations model, the LIFO model in short.

3.2. The Field of Research

The historical developments in commercial maritime transport at Turkish ports can be divided into three phases [13]. During the first phase in the 16th century, an agreement signed between the Ottoman Emperor and the French king permitted French flagships to trade in Ottoman-Turkish waters. During this phase, Turks were fishermen, ship chandlers, or small boat sailors who loaded and discharged ships at anchorage in bays. During the second phase that occurred between the 17th and 19th centuries, Austrian, Russian, Swedish, Spanish, and Prussian flagships were also permitted to carry out maritime transportation in Ottoman ports. In the third phase, which followed the foundation of the Turkish Republic in 1923, only Turkish flagships were allowed to be active in Turkish ports [13].

The Turkish fleet, which was initially made up of small sailing ships, was upgraded to steamships by the beginning of the 20th century [14]. By 1929, the Turkish Maritime Fleet consisted of 194 ships, 114 of which belonged to private Turkish ship-owners from the Black Sea region. Between 1923 and 1936, the Turkish maritime trade fleet increased further and by 1936, the net tonnage increased to 227,049 tonnes [13]. Beginning with small trade exchanges between Turkish and Black Sea ports, the regular migration of Turks from Romania, Bulgaria, and Greece made the maritime sector very attractive to entrepreneurs in the early 1900s [13]. Some ship-owners in Istanbul began as ship repairers. They repaired and transformed scrap warships into cargo

***Table 1.** LIFO variables in levels of institutionalization*

	Scholars/ Variables	Holm 1995	Spencer 1851	Durkheim 1897	Marx 1844	Weber 1904	Parsons 1951	Merton 1963	Sleznick 1943	Perrow 1986	Stinchcombe 1965	Berger & Luckmann 1966	Huntington 1968	Rowen & Meyer 1977	Zucker 1987	Scott 1982	Scott & Meyer 1983	DiMaggio & Powell 1991	Jepperson 1991	Tolbert & Zucker 1983	Oliver 1991	Greenwood & Hinings 1996
Pre-Institutionalization Level	Procedures	√				√			√				√	√	√	√	√			√	√	√
	Legitimacy	√				√				√				√	√		√	√			√	√
	Norms													√					√		√	
	Structure													√	√				√	√		
	Formalities	√													√	√				√		
	Power				√	√			√			√	√		√				√			
	Bureaucracy					√								√								
	Obedience					√	√	√														
	History								√			√				√				√		
	Processes			√											√	√			√	√		
	Organization										√											
	Accountability											√										
	Habits											√										√
	Recruitment																	√		√		
Semi-Institutionalization Level	Cultural structure						√												√			
	Impact on social env								√									√			√	
	Socialization								√										√			
	Informal structure								√													√
	Employee interest								√													
	Employee personality								√									√			√	√
	Social pressure								√			√			√	√	√	√			√	√
	Traditions											√	√		√						√	
	Knowledge											√										
	Aging												√									
	Isomorphism													√	√		√	√				
	Externality														√					√		
	Conflicts															√						√
	De-institution																			√		√
	Change management	√					√		√				√		√	√		√	√	√		√
	Environment																√					
	Identity													√								
Full Institutionalization Level	Efficiency													√	√			√		√	√	√
	Leadership													√								
	Continuity	√	√								√			√	√					√		√
	Future																					
	Stability													√	√							
	Trust													√								

LIFO: The Level of Institutionalization for Organizations

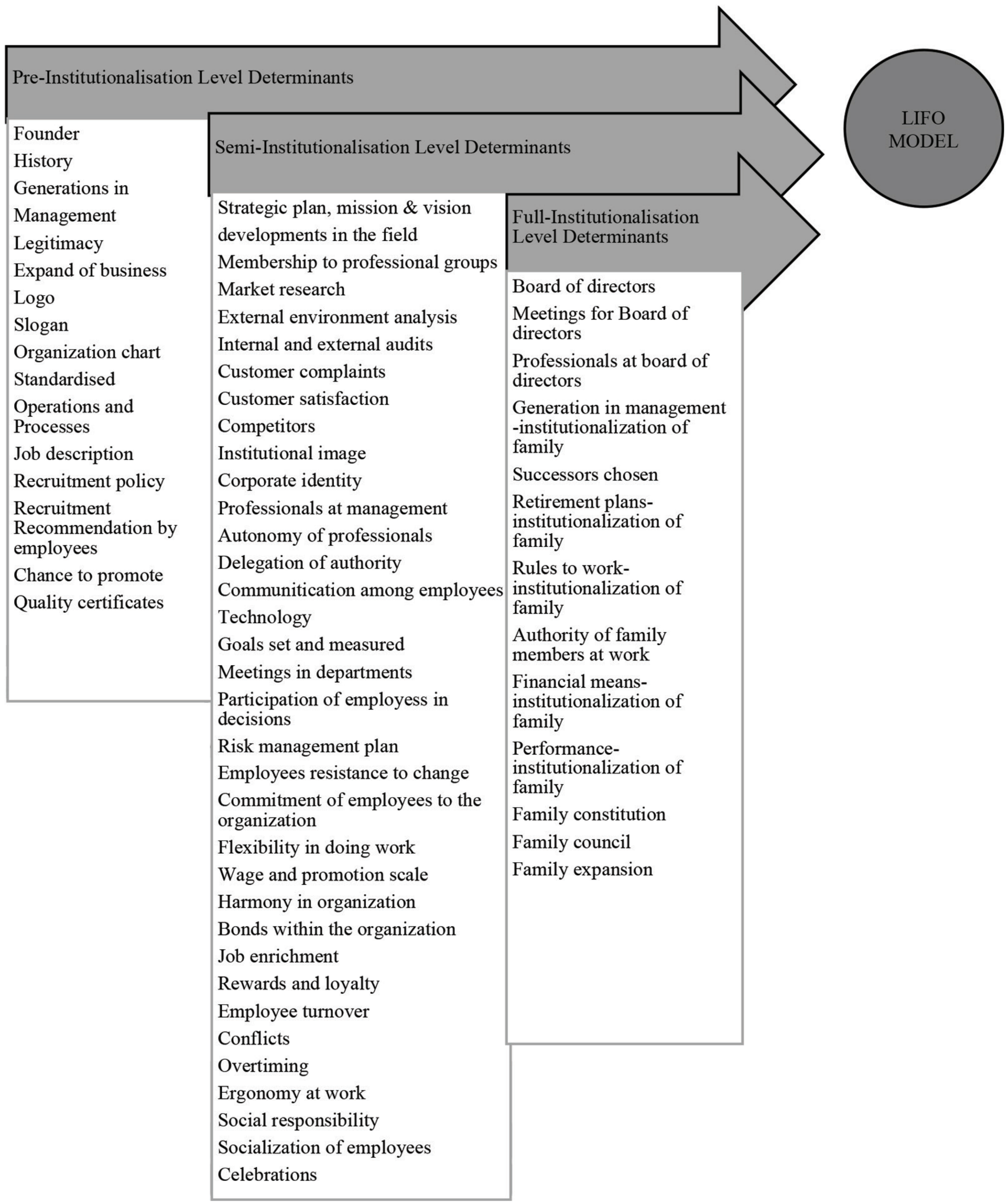

Figure 1. *LIFO model (Level of Institutionalization for Maritime Organizations)*

ships in the hope of economic gain and then engaged in maritime transportation. During the Second World War, many Turkish ships were sunk by warships and submarines [11]. After the war, new ships were added to the Turkish fleet. In 1951, there were 136 ships in total, 80 of which were owned privately, and the total net tonnage was 388,873 tonnes [25].

There was increased expansion of the maritime trade in the period between 1923 and 1962. The biggest problem in this period was the age of ships [10].

Public maritime transport developed with more significant momentum. However, after 1962, the number of private ship-owners increased [26]. The Turkish fleet had a deadweight tonnage of 7.3 million in 2006, 10.3 million of deadweight tonnage in 2012, and 8.5 million of deadweight tonnage propelling the country to the position of the 14th largest in size and capacity in the world in 2016. However, it should be noted that at present there are 551 ships with 8.3 million of deadweight tonnage in the national registry and 984 vessels with a deadweight tonnage of 20.9 million in the international record with an average age of 18.1 years [27].

In the search for historical development of Turkish ship-owning families, it is understood that the first generation of family-owned businesses in Turkish shipping started with wooden ships which were later upgraded to riveted vessels, then steamships, which were in turn upgraded to diesel engines.

During the World Wars, there were economic fluctuations. Turkish ship-owners and their families worked under harsh sea conditions and took risks, sacrificing a great deal for the family to gain better terms. Each new vessel was named after the relevant family patriarchs. Their children were obliged to take over the family business without being offered any other choice. Their workforce and education were predetermined based on the industry needs. Although sons advanced from apprenticeship to mastership in the family business, fathers did not delegate or share power with sons, and the last word always remained with the latter [14].

The experiences in Turkish transportation from ports to international ports [28], development in technical characteristics, tonnage, and values of ships, the increase in amount and value of cargos led to the need for insurance cover. There was a turning point due to environmental determinants [29] that forced Turkish ship-owners to meet classification standards for institutions, insurance companies, and protection and indemnity clubs and their demands [12]. When the businesses grew more prominent, increased branches and more employees were needed, institutional distance became an issue [30]. The founders were obliged to leave the luxury or freedom of independent decision-making, and started to work as a team, obey regulations, establish a system in coordination with the environment, and were forced to be "institutionalized".

3.3. The Methodology of Research

The LIFO model was developed for collecting data using face to face interviews with the heads of ship-owning families as a collaborative social research. Contributions from heads of families are considered the most appreciated source for institutional memory, the most accurate and the most precise of points of view. Additionally, their inner thoughts were anticipated to be the focus for the purpose of the empirical research. Due to its nature, the semi-structured questionnaire form was preferred for collecting data because if a question became necessary, it could be included in the research and interviews.

During the development of the LIFO model, a semi-structured questionnaire form containing 61 questions was prepared to obtain data. There were four questions for the phrase of institutionalization and its contents, 17 questions for the pre-institutionalization level, 27 questions for the semi-institutionalization level, 13 questions for the full institutionalization level. In this form, open-ended questions and closed-ended questions were used. The closed-ended questions had options of three different scales, namely, completed (yes), not completed (no), and partially completed.

For the external reliability measures, the recommendations provided by LeCompte and Goetz [31], for qualitative researches were applied. For external reliability, all the interviews conducted by a single interviewer, the interviewees were defined clearly, the way and the process of interviews carried out was outlined; the data collection approach and methods of data analysis were described in detail. Similarly, for the internal reliability measures, the data collected was presented directly first and then the discussions were provided in the research. The council consisted of the University of Dokuz Eylul members of the faculty of maritime studies and organization theory studies, the observations provided by the sector were found to be in line with the findings. The model and its levels were defined before data collection.

The reliability and validity of the questionnaire form were tested using two different methods. First, a meeting was arranged with an academic council specialized in maritime logistics and/or organizational theory from among Dokuz Eylül University faculty members. Corrections were made to the questionnaire in line with their criticism and suggestions, and the interview questionnaire form was finalized. Secondly a pilot test was carried out.

The pilot test was conducted with a family-owned shipping organization which took 90 minutes. The pilot study was found satisfactory for developing the model. As a result, the final form of the LIFO model was accepted and the semi-structured questionnaire finalized as shown in Table 2.

3.4. Population and Sample

The number of members registered at The Chamber of Shipping as ship-owners and ship operators was 1491, some of whom either had no vessels or were inactive in business in 2016. In order to determine the number of members, The Chamber of Shipping provided a list of Turkish flagships

Table 2. *The semi-structured questionnaire for LIFO*

Part l	
1	What is institutionalization according to you?
2	What are the specifications of an organization that declares itself institutionalized?
3	Do you think your organization is institutionalized? Yes/No/Partially
4	What are the reasons of your answer?
Part ll	
5	Who is the founder?
6	Is the founder still in management? Which generation currently manages the company?
7	How many partners established the business? What is the number of partners today?
8	When was your company established?
9	What is the legal structure of your company?
10	What are the fields of activity of your company?
11	Do you have a logo? Since when do you have logo? Is the logo patented?
12	Do you have a slogan?
13	Is there an organization chart?
14	Have job descriptions for each position been made?
15	Are the operations and processes standardized? Are the operations written down?
16	Do you have a handbook for the operations and processes?
17	Is there a written policy for recruitment?
18	Is there a practice of recommending new personnel by employees?
19	Are there any subordinate staffs who have reached management positions?
20	What are the quality certificates related to the field of activity?
21	What was the last change in the company?
Part lll	
22	Is there a strategic plan for the company? What is the strategic plan that is aimed to be realized in the shortest term?
23	Do you have vision/mission statements and are they printed for display on the walls? What is your opinion about the vision/mission statement?
24	Has a precaution plan been made in advance for possible problems?
25	Does the company have a corporate identity understanding? How would you describe the corporate identity of the company?
26	Is there an electronic database program used within the company? How do the departments communicate during business operations?
27	Is there an institutional image determined by the management? How would you describe the corporate image of the company?
28	Has the company been involved in social responsibility projects? Could you give brief information about your Social Responsibility project?
29	Does the company have a membership in professional groups? Which is it?
30	Is market research done? Is an external environment analysis done?
31	Is information collected about competitors? How are the developments in the industry followed?
32	How is customer satisfaction measured? How are customer complaints handled?
33	Are there internal and external audits? How often are they performed?
34	Are there any professionals in the management? Is control and management left to professionals? Do business professionals have decision-making autonomy?
35	Do managers have a say in recruiting a subordinate staff member? And/or in firing a subordinate employee? Which departments are managed by family members?
36	Are goals measurable and time-frame set? Do employees work in harmony to achieve the goals of the company?
37	Is there a clear and written promotion scale and wage scale? Are employees rewarded if corporate goals are achieved?
38	What is the employee turnover period? Are employees loyal to their jobs? How would you express the level of commitment/trust of the employees to the business?

Table 2. *The semi-structured questionnaire for LIFO (Continued)*

Part lll	
39	Are employees allowed flexibility in doing work? Is the decision to work overtime in the company easily implemented?
55	Are there procedures for family members to work in the business? What are these procedures?
56	Do family members take part even if they do not have sufficient education/skills?
57	Are there any rules regarding education/gaining experience for the young generation who will take over the management? What are these rules?
58	How does authority and responsibility work when it comes to family members?
59	Are there any restrictions for family members' remuneration or expenditure in meeting financial needs? What are the restrictions?
60	Are family members also subject to performance controls? How is this performance audit done?
61	Is there a family council? Who are in the family council? What is the frequency of the family council meeting? Is the family council meeting agenda being created? Are meeting decisions communicated to all members of the council?
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for commercial cargo ships. Since there is a tradition of registering each ship under a different company title, 433 companies were identified as active ship-owners from of this list. To avoid duplication, names with the same addresses and/or phone and/or fax numbers were grouped and a population of 244 ship-owners was determined. Of these, 116 had one vessel, 52 companies had two vessels, 25 companies had three vessels, 18 companies had four vessels, 7 companies had five vessels, and 14 companies had six vessels or more at the time of the study.

In a meeting with the members of The Sea Transporters Association and The Chamber of Shipping in their Izmir Branches, we were advised to focus the sample frame of Turkish ship-owners with at least three vessels and a minimum deadweight of 1000 m tonnes for each vessel. Thereby the sample was to consist of 64 companies.

3.5. Data Collection

Several methods were used to reach the ship-owners: (a) e-mails sent in April through May 2016, (b) phone calls were made as reminders. (c) Several in-person meetings were arranged with some ship-owners during the 6th Joint Commissions Meeting of Commerce of Shipping in Istanbul. (d) A meeting was arranged with the Istanbul Turkish Ship-owners' Association to request their help in obtaining appointments. (e) Another meeting was also set with the Association of Istanbul Ferry Equipment and Agencies to explain the purpose and the objectives of the study as some members of these associations are also ship-owners. Seven monthly meetings of The Chamber of Shipping held in Istanbul (f) and Izmir (g) were attended. Eventually, between April 2016 and May 2017, two interviews in Izmir, and 18 interviews in Istanbul were achieved.

In the interviews conducted through the heads of the families as ship-owners, notes were taken by hand to maintain privacy. Taking notes by voice-recording was not suggested. Interviews were held in their offices to create a familiar setting in the usual workplace [32]. The data was collected by the collaborative social research approached [33]. There was no time limit; the shortest meeting took 60 minutes and the longest 180 minutes. The questions in the questionnaire form were asked one by one, regardless of relevance for consistency and all information provided was taken into consideration.

At the end of each interview, the interviewees were asked whether there were any misleading or missing questions, or information, and according to the ship-owners, whether the questions were satisfactory and meaningful.

3.6. Methods of Analysis

The notes taken during interviews were fed into the computer at the end of the day to avoid missing abbreviations and in the notes in the data [12]. The data was collected through open-ended and close-ended questions by the semi-structured questionnaire.

The data obtained through the open-ended questions was analyzed by summarizing content analysis [33]. The data was made into text. The text was then categoried by identifying similar phrases, expressions, patterns, concepts and relationships as codes. These codes were transformed into categorical labels or themes according to [12]. Words, themes, and concepts in the data were subject to coding for analysis [34]. Data coding, finding themes, arranging codes and themes, and defining and interpreting the findings were the four stages applied to conduct content analysis of the questions prepared for the research topic [35]. These codes were then counted as words, and themes [33]. In addition to textual content analysis, the data was analyzed in percentages for quantitative presentation [36].

The data obtained through the close-ended questions was analyzed in quantitative comparison and weighed according to the tonnage of the ships operated by the ship-owners as a percentage of total tonnage in the study.

4. Findings and Discussions

Is the research population is 433 companies; the sample is 64 companies that are Turkish ship-owners with at least three vessels of 1000 m tonnes and more. The heads of family-owned shipping companies representing 50 companies, (78% of the sample) were interviewed.

Representatives from 78% of the companies were interviewed during data collection. The heads of families voluntarily talked about the histories of their businesses. In institutionalization, the history of the business and its impact are both required for its social environment [2]. The results of the interviews reveal that 54% of the companies were established before the 1900s, 16% of them between 1960 and 1979, 26% between 1980 and 1999, and 3% after the year 2000. The founders of 26% of these companies were the interviewees themselves, 26% of the companies were founded by the interviewees' fathers; 1% by the grandfathers, while 52% by the great-grandfathers. With regard to the type of work, business operations were related to ship-ownership for 29%, ship operations for 11%. Four percent of them worked in port management; 7% with tugboats, 7% in ship broking, 7% operating shipyards, and 2% sand transportation. Only 31% of companies interviewed were involved in non-sea transportation such as oil station operation, ready-mixed concrete production and sales, mining operations, and chemical trade.

In the analysis of the LIFO model, the findings related to each level of institutionalization were presented separately and discussed in line with the literature review.

4.1. Pre-Institutionalization Level of LIFO Model

Seventy eight percent of the ship-owners interviewed are incorporated companies while 22% are limited companies. All these companies have logos, 84% of which are patented. Identity is a concept observed through the naming of an institution's service [37]. This is also the case for logos, letterheads, vehicles design, and general appearances of buildings, interior decorations, salespersons' behaviors, and managers' profiles. Institutionalization is the acquisition of an identity and is a sensitive and flexible organism as the natural product of social needs and pressures [8]. Seventy percent of these companies define themselves by creating slogans. Corporate identity and corporate image are by-products of the slogans created. Marks and emblems on the funnels of vessels are also a part of the corporate identity. It is an adaptation to the corporate environment [10]. Organizations would be institutionalized by formal structures rationally organized to achieve goals. On the other hand, organizations are subject to social pressures, government expectations, and directives, business practices that dominate the industry, and institutional pressures. Thereby their structures are formed. The formal structure is to determine in advance who is doing what and the processes and forms of systems [8]. With a formal structure, the heads of families of 95% of the companies stated that their organizational charts were partially defined while 2% stated that the companies were fully defined. Operational processes in the company are entirely defined by 34%; partially defined in 63%, and undefined in 3% of the companies. Job descriptions are precisely defined by 71% and partially by 25%. Written procedures are fully prepared by 87% and partially by 7% of the companies. Formal structure allows an organization to be an institution; without social pressure, organizations do not turn into institutions [38]. In line with this view, while doing business in accordance with the job descriptions and personnel adherence, family businesses in sea transportation coordinate relations with the agencies in the external environment, freight holders, parties to the transportation contract, and other organizations such as forwarders under national and international maritime social and legal pressure.

The number of personnel working in the formal structure is one of the elements of institutionalization. Fewer staff indicates a higher level of institutionalization; the ease of innovation will be more effortless in small organizations. The higher the number of organizational functions and the levels of hierarchical order, the higher the institutionalization level [37]. The heads of families stated that there are up to 200 land personnel in 4%, up to 100 in 10%, up to 500 people in 18%, up to 50 people in 22%, and up to 25 people in 45% of the companies surveyed to carry out their functions. Human resources policies are set by 42%, and partially set by 47%. The existence of human resources policies is a symbol of legal formalization and an example of both standardization and formalization, such as not employing uninsured personnel, stipulating the adequate number of ship personnel, having the necessary documentation of ship personnel.

After data analysis, Figure 2 shows the variables of the pre-institutionalization level of the LIFO model.

4.2. Semi-Institutionalization Level of LIFO Model

Twenty-three variables in the LIFO model define the semi-institutionalization level. The first of these variables is the tools of strategic management. It was determined that 69% of the companies have strategic plans, while 24% of them have partial plans. A written mission statement is available in 37% of the companies, while a written vision is available in 47%. The short-term targets of the companies were expressed in such comments as follows: "Targets that are revised frequently according to the

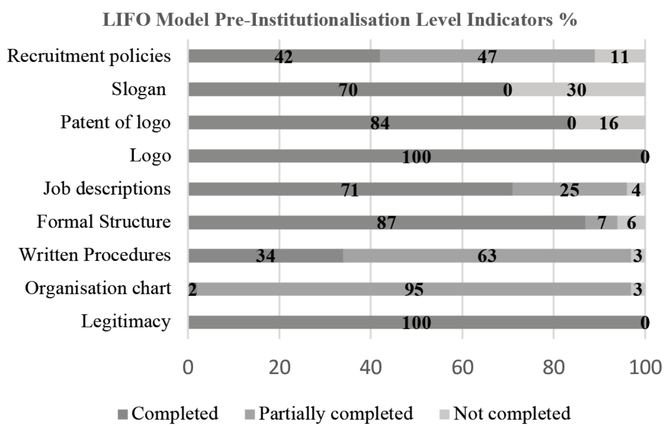

Figure 2. *Pre-Institutionalization level indicators of LIFO model*

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market," "non-existent," "it is an instant decision-making period," "the light at the end of the tunnel is either the approaching train or the unknown," "get rid of the ships," "refresh the fleet, start thinking about buying new ships," "retiring."

Businesses need a corporate identity for their rational structures that allow them to access resources. To form the corporate identity, the first step is to create the corporate image [10]. Corporate image reflects who the company is, how and what they do. Corporate philosophy indicates clues [39]. In this study, the corporate images were expressed by the heads of the families using an average of 11 words. The most commonly used were "reliable" by 23%, "ethical" by 23%, and "reputable" by 16%. The heads of ship-owning companies provided their descriptions of corporate identity by using an average of 17 words. The most commonly used expressions were "having standards" by 12%, "having respectful reputation" by 12%, "being reliable" by 7%, "Being Honest and Ethical" by 12%, and "innovative and open to developments" by 12% of the companies.

In the LIFO model, customers and customer relations are criticized based on several variables. For ship-owners, charterers are also called customers. It has been expressed that charterers are in a stronger position against ship-owners due to the crisis suffered since 2008; therefore, ports not pre-visited or cargos not accepted are all in their agendas. The heads of families' state that the charterers' complaints are based on unreturned phone calls regarding vessel delays resulting in "letters of protest" which are eliminated mostly by reducing invoices issued and enhancing service quality. One of the elements of institutionalization is to reduce the dangers of its existence to the organization; therefore, it is generally expected that the companies should provide customer satisfaction, become a learning organization, gain organizational identity, and achieve long term goals instead of short-term ones [37]. In this study, it was found that customer satisfaction metrics are based on the "continuity of charter agreements" and "fewer claims". For the sustainability of the company, market research was carried out on charterers by 94% of companies using various indexes, publications, and reports. Professional support was requested by only 3% of the companies. It is understood that personal experience and feelings of the heads of the families are prioritized.

Organizations working in the same field face similar environmental pressures and have structures and functioning parallel to the environmental expectations and challenges. Thus, institutional isomorphism emerges [11]. The companies follow the developments in the industry, so a similar isomorphism emerges. In this study, the coercive isomorphism of DiMaggio and Powel [11] matches Turkish ship-owners' International Safety Management practices and compliance with international conventions is compulsory for maritime transport activities. Another example of compelling and normative isomorphism was tanker management self-assessment applications in tanker companies. As Oliver [40] puts forward, the expansion and balancing of structural innovation in organizations is an attempt to achieve equality between multilateral partners and private interests.

These indicate the changes in the institutional structure to overcome complexity and the reduction or prevention of their effects. Institutional change refers to change in institutional form to ensure continuity [38]. Changes in the economics, insurance, banking, and shipyard arrangements are results of downsizing since 2008. In this study, it was found that Turkish ship-owners prepare themselves for environmental changes by following such sources as print and social media, sectoral publications, and reports, Lloyds List, etc. The meetings in The Chamber of Shipping, Turkish Ship-owners Association and The Baltic and International Maritime Council, professionals, and friends are other sources. As these are the environmental indicators, ship-owners' business policies are revised accordingly.

In this study, 73% of the companies stated that they prefer warnings and persuasion to manage personnel who resist change for adaptation. Employees' reactions as well as organizational actors to institutional change can be observed. These responses are expressed as passive to active, namely sequencing, submission, compromise, avoidance, resistance and manipulation [40].

Manpower and relationships with employees are crucial aspects for organizations. These aspects are the points of focus at the semi-institutionalization level of the LIFO model. It is understood that there are two ways for personnel to address themselves. The formal way, which entails reference by titles such as Mr./Mrs. or Captain, is observed by 44% of the companies. It can be accepted that the ways of addressing each other are influenced by the values and traditions of the ship-owners' family, business and employees [10]. Normative isomorphism refers to the uniformity of personal behavior patterns, the style of clothing, and the words they use in speech and jokingly, and the way they choose to speak [11].

It was reported that employees have been working for a long term in 68% of the companies. In 38% of the companies, some employees have been working for almost 40 years. In 26% of the companies, employees have been working for 30 years. There are even employees in 1% of the companies who have been there for more than 40 years. They are considered to be as reliable as the family members. The rules established between two people are transmitted to the third person as sacred orders, and those who contribute to the formation of the rules are more prone to implement them and thus raising the level of institutionalization in the organization [2].

In normative isomorphism, the emergence of uniformity is by professionals and their memberships in professional organizations. The longer they stay in a company and keep their contact with other professionals, the more opinions are exchanged and shared [11]. Disagreements and conflicts between personnel are solved by changes in management methods in 22% of the companies; by convincing each other peacefully in 23% of the companies, and by solutions declared by the boss in 55% of the companies. It was understood that personnel have promotion and job enrichment opportunities. Managerial positions are open to substitutions, and the rate of promotion is 98%. Job enrichment and rotation of personnel are available at 57% of the companies. Training opportunities are offered to personnel in 70% of the companies. A monetary reward system was applied to personnel in 85% of the companies if targets were met. Compliance with individual or organizational objectives is needed to exist as one of the necessary elements of institutionalization [37].

Job enrichment is achieved by working toward the goals of the whole organization [41]. In Turkish ship-owning companies, there is limited employee autonomy. However, 75% of companies did allow autonomy among professionals but only for operational decisions. Routines are indications of institutionalization. Managers must establish and maintain routines.

The institutional field affects the direction and type of change; therefore, managers should have autonomy [42]. The members of the family manage critical areas such as accounting, finance, human resources, and chartering. The heads of families' state that the delegation of authority to professionals and family members only exists for operational decisions. Having different practices for risk assessment and having a watchful eye on professional from both sides might have conflicting objectives, and having a professional who puts his interest forward or makes decisions that do not match the interest of owner would be costly [43]. The relationships between the principal and the agent are applied to the ship-owner and the professionals employed in the company. In this relationship, a professional is supposed to serve the interests of the business. The agency problem is the base of un-delegated authority [44].

However, there are situations in agency theory where an agent is not sure of the owner's decision due to differences between the objectives of the owner and those of the agent [45]. Such problems could be attributed to the nature of the maritime business; the leader of the family business may need immediate reaction to situations, which would be explained by the contingency approach.

The contingency approach focuses on making instant decisions about how, when, and what will be done depending on the changing conditions [46]. There are no universal principles or methods that are applicable in all cases everywhere. The main task of owners is to determine the most appropriate method to achieve the goal in a situation given.

Owners tend to innovate and identify methods and strategies appropriate to their circumstances. Environmental factors are independent variables. The structure is a dependent variable. Contingency is about providing an active organizational order that will best adapt to the situation characterized by the environment, technology, size, resources, and other factors under which the organization operates. Organizational roles, experiences, beliefs, and ideologies are effective in individuals' perceptions of their environment. At this point, the most critical element is the leader [47,48].

Institutionalization is explained as the process in which social responsibilities and behaviors acquire rule-like status. Seventy one percent of Turkish ship-owners have contributed to social responsibility projects to an extent. These projects included financing a railway bridge, school and faculty classrooms, hospital units, and health centers to carry on the family name. They also stated that they provided private scholarships and supported students.

The findings for the semi-institutionalization level of the LIFO model are shown in Figure 3.

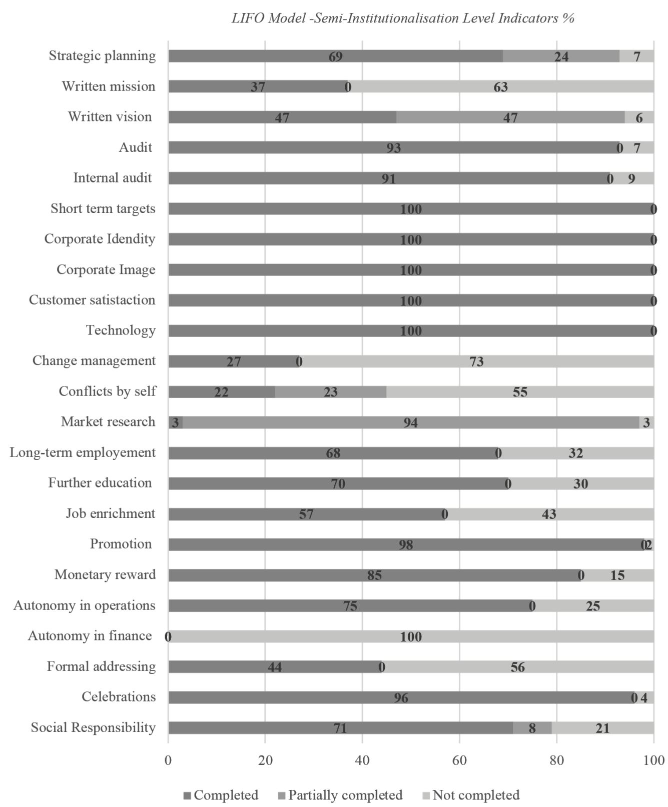

Figure 3. *Semi-Institutionalization level indicators of LIFO model*

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4.3. Full Institutionalization Level of LIFO Model

The harmony family and business institutionalization was examined at this level. In the LIFO model, the full institutionalization level is defined based on nine variables and one generation level indicator. At this level, variables related to the age and sustainability of the company is discussed. Three percent of the companies interviewed have been in business for less than 20 years; 26% for approximately 40 years; 16% for 60 years, and 54% for about 100 years. As most companies in the sample are a century old, the level of institutionalization is expected to be high. The reason for this assumption is due to Huntington's study based on the measurement of institutionalization of organizations by adaptability, complexity, autonomy, and compliance. To this end, the age of the organization can measure adaptability. There are three different methods for this measurement: chronic age, generation age, and functional age [37]. Based on the establishment of the companies interviewed, the level of institutionalization was expected to be high according to chronical age.

The power in business management was determined to be in the hands of the 1st generation in 10% of family-owned businesses; 1st and 2nd generation together in 29%, 2nd generation in 23%, 3rd generation in 8%, 3rd and 4th generation in 4%, 4th generation in 19%, and 5th generation and more in 6% of the companies surveyed. Despite the increase in organizational generational age, consistency of the management methods may cause failure in organizational adaptation. The level of institutionalization within the organization increases in parallel with the generation change of the leaders. Generation age is a function of chronological age [37]. Despite the changing internal and external environments, the fact that the first and second generations remain in management is a problem [37].

The heads of families define their self-assessed level of institutionalization with an average of 34 words. Fifteen percent of the companies that accept themselves as not being institutionalized maintained that "there would be no institutionalization in maritime business" and "business would not continue without a boss". Further, 47% of the companies that accept themselves as partially institutionalized stated that "there would be no professional qualified enough to know what he is doing" and "there would be no professional trusted enough to delegate the business to. If such a person existed, she/he would leave to establish his/her own business". Conversely, 39% of the companies that accepted themselves as fully institutionalized asserted that in their businesses, "job descriptions are made and autonomy borders are drawn", "business is delegated according to these lines" and "professionals are free to make decisions within the limits of their autonomy". Sixty-five percent of companies had non-family professionals who have been working with a family for more than 25 years. Sixty-three percent of these professionals were also found to be included in the board of directors. The head of families said that these professionals reached their positions by experience from the very beginning of the business mostly at the side of the founder. Unlike other professionals, they mostly have no formal training in business administration, but they are committed to the family with respect and loyalty.

In addition to conducting the board of directors meetings in the manner and frequency required by law, the top management meetings with the chairman of the board of directors were held "frequently" in 30% of the companies, and similar meetings were held once a month in 10% of the companies.

There was a designated successor among family members working in 63% of the companies, 14% of the companies that had no determined a successor said they would delegate the business to professionals in the future. There were five members on average working for family businesses. It was found that 26% of the family members working in the enterprises served only as members of the board of directors, 26% in chartering and fleet management, 24% in finance and accounting management, 7% as general managers, 5% in sales and marketing management, 2% in personnel management, and 2% in purchasing management.

There was no official performance criterion assessment for family members. However, 79% of the companies had programs for young family members of undergraduate and graduate level to gain experience in the company.

Families expand through marriage and childbirth. The family constitution is thus crucial for family institutionalization. Setting rules for family constitution is advised [24]. The heads of families in 26% of the companies stated that these rules are available in written form, in verbal form, or in the formation stage in 8% of the companies. A family council is a setting in which formal meetings are held; and responsibilities are shared among young members of the family to prepare them for business under the leadership of elder members and professionals [23]. This system was available at 19% of the companies. The heads of families said that having large weekend lunches/dinners has replaced the meetings recommended for the family council for the preparation of young family members for business and the future in 6% of the companies.

Findings related to the full institutionalization level are shown in Figure 4.

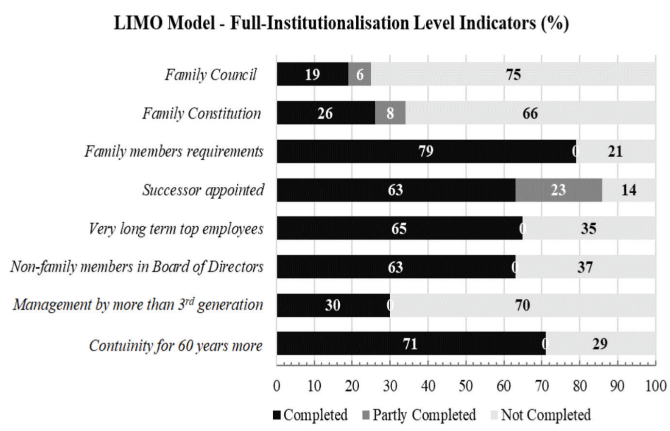

Figure 4. *Full-Institutionalization level indicators of LIFO model*

Study Limitations

This is the first study based on the institutionalization of ship-owners as maritime organizations. The heads of the Turkish ship-owners were not willing to contribute to the research; therefore, some of the families/companies in the sample could not be pursued. The interviewees could not be categorized according to the size of their vessels, or the type of cargo they carry, or according to the ports they frequently visit. Some of the interviewees felt irritated answering questions related to family, its members, family constitution and family council. Sea transportation and ship-owners experienced a crisis from 2008 to date thus some of the answers provided by heads might be due to the influence of the financial and emotional stress. The search indicates the results up to 2018. However, according to a report issued by the Chamber of Turkish Shipping, there was a difference of -7.25% between 2018 and 2019 and -3.70% between 2017 and 2018 is -3.70 in total deadweight of the vessels in Turkish flag and ownerships for 1000 grosston and over. According to the annual report issued by the Ministry of Transport and Infrastructure the Turkish fleet remained the 15^{th} biggest fleet in size in the world between 2016 and 2020. The extent of the business has not been altered much, as the families and their heads are conservatives and the businesses and their attitudes are expeted to remain the same.

5. Conclusion

This research contributes to the institutional theory by developing a model for an innovative approach to harmonize family and business at the institutional level with 68 variables derived from institutional theory. With the model, the institutionalization levels of each company can be evaluated independently at all three defined levels.

The study also contributes to family businesses in maritime transportation as the LIFO model was used to determine the institutionalization level of Turkish ship-owners in general as family-owned businesses. Each ship-owner company was evaluated separately, and the data were gathered, and a cross-sectional analysis of the institutionalization of Turkish ship-owner Companies is presented. Using the model, a scale is available to show which variables are missing at each level and which regulatory and preventive activities can be performed by companies.

From the empirical findings and theoretical interpretations reported in this article and in conjunction with consideration of the data, we conclude that a pre-institutionalization level of the LIFO model for Turkish ship-owners was achieved by Turkish ship-owners' companies. The results reveal that the establishment and formalization of these organizations were set on firm bases.

Using the semi-institutionalization level of the LIFO model, it was determined that variables were at different levels across the departments within organizations. The results reveal that there were fluctuations in doing business and differing attitudes among organizations in the same field. The main problem is lack of trust in and the autonomy of professionals. The delegation of management to professionals was impossible for ship-owners. Agency theory can explain this result.

The companies and families have not achieved the determinants of the full institutionalization level of the LIFO model. The results reveal that there are already existing problems or problems that are likely to emerge very soon in family sustainability and institutionalization. The main problems can be summarized as follows: Family members and businesses face uncertainty due to the family rules, lack of performance/payment balance for family members, the lack of participation of the family council in the preparation and development of young family members for business continuity, reluctance and lack of confidence in delegating authority to younger generations, as is seen in the agency theory. The head of the family believes that he can evaluate the situation best by him/herself, and due to the nature of the sea, only s/he can determine the right direction for the company interests as is seen in the contingency theory theoretical perspective.

When the evaluated findings were shared with the participating companies, they stated that the results reached were very satisfactory and gave guidance. As intended by this study, the LIFO model can be used not only in maritime organizations but also in structures in which there are many family business arrangements.

Recommendations for Further Research

A similar study can be carried out by sorting companies by cargo carried and ports visited by ship-owner family businesses. The LIFO model can be applied to Turkish coaster-owner family businesses, which are nowadays under legislative development and on the governmental agenda.

Authorship Contributions

Concept design: K.O. Turhaner, S. Nas, Data Collection or Processing: K.O. Turhaner, S. Nas, Analysis or Interpretation: K.O. Turhaner, S. Nas, Literature Review: K.O. Turhaner, S. Nas, Writing, Reviewing and Editing: K.O. Turhaner, S. Nas.

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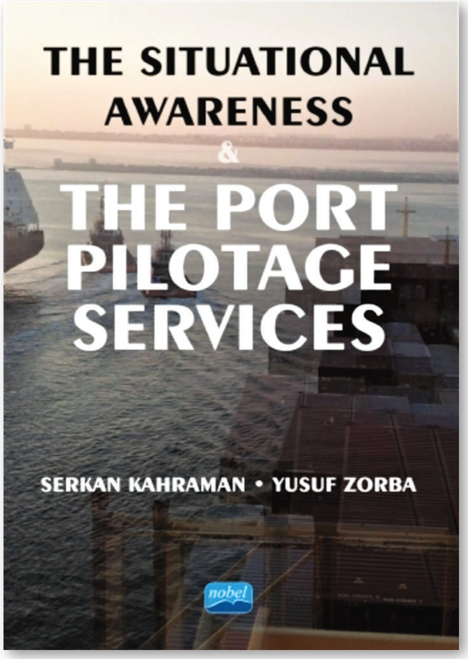
The Situational Awareness & The Port Pilotage Services

Authors: Serkan Kahraman and Yusuf Zorba

Reviewed by: Capt. Numan Cokgormusler, Ph.D.
Unlimited Master Mariner, Senior Harbour Pilot (Nemrut Bay and Port of Akcansa)

Keywords: Situational awareness, Maritime pilotage, Techno-nautical services, Port pilotage



The main idea of the book includes valuable research on the effect of situational awareness and safe ship maneuvering in port pilotage services for the first time. In terms of scientific results, this study is both fascinating and remarkable. In the development of this research, a detailed, sufficient literature study was conducted. In addition, as evidenced by the results, this research elucidates studies that should be conducted in the future. Thus, I believe the book will be significant in the future.

The topic that the findings of this exceptional study raised for discussion is situational awareness in terms of scientific data, including its effect on life/property and environmental safety while providing port pilotage services, the difference it creates, the factors and components affecting it, and its relevance to safe maneuvering.

The two researchers who conducted this significant study and wrote this book have resumes and professional and academic careers that distinguish them as people with the highest level of qualification and skills required for conducting scientific research on this subject.

Mr. Yusuf Zorba, a graduate of İstanbul Technical University's Maritime Faculty with a bachelor degree in Maritime Transportation Engineering, has worked at various officer levels on ships of major chemical transportation companies in the Turkish maritime trade. Mr. Zorba is a valuable academician who works in maritime transportation engineering and management science fields, continuing his career as an Associate Professor at the Maritime Faculty of Dokuz Eylul University.

Mr. Serkan Kahraman earned a bachelor degree in Maritime Transportation Engineering from the Maritime Faculty of Istanbul Technical University and has worked in various positions on ships of major Turkish maritime trade companies. He has also worked as a pilot in the Turkish Straits, Port of Canakkale, Port of Izmir, and DP World Jebel Ali Port. Mr. Kahraman currently works as a pilot in Port of Tuzla and the Tuzla shipyards region. He is a valuable

Address for Correspondence: Capt. Numan Cokgormusler, Ph.D., Unlimited Master Mariner, Senior Harbour Pilot (Nemrut Bay and Port of Akcansa)
E-mail: ncokgormusler@yahoo.com
ORCID ID: orcid.org/0000-0001-7801-3563

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researcher who is also pursuing a doctoral degree owing to his interest in academia.

The first section of the book aims to provide general information about sea transportation and pilotage. Accordingly, maritime transportation was defined, and its global significance was revealed. Afterward, an attempt was made to explain port operations, ship services, and techno-nautical services. Pilotage services, as well as related international regulations, were mentioned as one of the services, with a focus on the laws and operation of pilotage services. Private and non-governmental organizations that work closely with ports to offer pilotage services in Turkey were also mentioned in the first chapter.

There was an attempt to disclose the importance of situational awareness for port pilotage services in the second section of the book, which emphasizes the relationship between pilotage services and safety. In the succeeding sections, the concept of situational awareness, its components, measurement methods, and measurement techniques are all discussed in detail. The places where situational awareness studies were conducted, as well as situational awareness studies on sea transportation, are evaluated at the end of the section.

The third section includes the simulation scenario created using the situation awareness global assessment technique, as well as the conducted experiments and findings for the above-mentioned objective. The conclusions made based on the findings are briefly stated.

The strength of this work, which deals with maritime transportation, a scientifically important subject, is that it is a reference study with its research model, sampling methods, and scientific methods clearly expressing the data on the subject, including its content and methodology. It also stands out as guiding research that highlights new studies that should be done in the future.

It is apparent that improving the international aspect of the field-specific, detailed research presented in this book would be beneficial, because, in my professional life, I have observed that situational awareness is related to education, service conditions, quality standards, and culture in the countries where service is received/provided. Owing to the aforementioned factors, evaluating the application as a single-country and single-nationality research limits the data, particularly during the procurement of the subject service. Thus, to determine the accuracy of evaluations, they must be developed and implemented in the future. I believe that the research should be considered a new and developing area for researchers in this field, and its positive and negative effects on the situational awareness of captains and/or pilots should be investigated in future studies. In addition, in the discussion section of the book, the general assumption that pilots "have been ship captains before" is considered, and the development of experience is conveyed. Some countries do not have such a requirement for pilots. Therefore, another point to explore is if the time spent as a captain and the experience affect the situational awareness of the pilotage service or if there is a correlation between the two. Notably, the fact that it causes us to consider all these issues is a compelling reason to examine and evaluate the book.

Viewing the book from a general perspective, it is apparent that no previous study or research of this scope and type has been conducted on a sectoral basis. Thus, I believe that the book will be a valuable resource for professionals and decision-makers working in the maritime industry, particularly researchers/authors. In addition, I acknowledge all who contributed to the emergence of such a significant work and its application to the maritime industry. I hope that the maritime industry will benefit from this work, which I believe will elucidate and guide similar and more specific studies in the future.

Dr. Capt. Numan Cokgormusler

Dr. Capt. Numan Cokgormusler graduated from the Maritime Faculty of Istanbul Technical University with a degree in Maritime Transportation Engineering in 1992. From 1992 to 1996, he worked on ships at various officer levels before becoming a lecturer at Dokuz Eylul University's Maritime Business and Management School. After completing his doctoral studies in Maritime Economics at İstanbul University, he worked as a visiting lecturer at Maine Maritime Academy in the USA. In 2000, he returned to sea service, and in 2003, he began a maritime pilotage career with UZMAR Pilotage Co. in the Nemrut Bay area. Since 2015, Dr. Capt. Numan Cokgormusler has been serving as a Master in the Turkish merchant fleet.

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