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EDITORIAL(ED)
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Editorial

We are pleased to introduce JEMS 8(4) to our valuable followers. There are valuable and endeavored 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, to our editorial board, to our section editors, to our foreign language editors who provide quality publications by following our publication policies diligently and also to layout editors who spent great efforts in the preparation of this issue.

Your Sincerely.

Prof. Dr. Selçuk NAS
Editor-in-Chief

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Dimensions of the Port Performance: A Review of Literature

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ABSTRACT

The port performance has frequently been studied in the academic literature, and the first studies on the subject are focused on financial or operational dimensions. However, today, port performance has become multi-dimensional due to the changing roles of the ports to its stakeholders, and the fact that local competition has been replaced by global competition through continuously developing routes, etc. Within this study, it is aimed to determine each dimension of the port performance concept which had been handled as a multi-dimensional process in recent years in literature. For this purpose, port performance literature is reviewed and frequency analysis of the related studies was made. As a result of the analysis, dimensional perspective was brought to the port performance concept and the indicators of each dimension used in empirical studies were gathered together. So, the concept of port performance had been divided into four basic dimensions which are operational, financial, sustainable, and logistics. Finally, dimensional gaps in port performance literature were revealed and some suggestions were given for further studies.

Keywords

Port Performance, Performance Dimensions, Performance Measurement, Operational Performance, Sustainable Performance.

1. Introduction

Developments such as the expansionary force of globalization, the transfer of the seat of efficient units to the countries with low input costs, the adaptation of market economies by more countries, the mounting pressure on decreasing transportation costs, the market for agility in transportation, the politic and structural changes including more autonomy in port management, the inclusion of state of the art technology in loading and discharging process, etc. require ports to be more efficient and advantageous [1].

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These developments also increased the performance of the competition between ports [2]. While high port competition and increased carrying capacities of ships demand a better port performance, this performance largely depends on port characteristics such as infrastructure, expertise in cargo handling, shipping services, and the level of integration into freight networks [3]. In short, in today's supply chain era, both the demands of customers and the necessities of the global competitive environment force the ports to continuously improve their performance [4]. Therefore, ports need to measure their performance at regular intervals to improve their performance. In general, ports need performance measurement to measure their efficiency, effectiveness, how they have been compared to previous years, whether they have met their targets, their situation against competitors, and to gain new customers by promoting their business [5].

Ports are the hubs of the shipping, so, the performance of a port has direct and indirect effects. Therefore, the measurement and the monitoring of the ports' performance are very important to maintain the development and economic success of the countries [6]. Performance measurement results are the most important data input for regional port planning and operations [7][8]. In this age when creditworthiness is difficult, one of the most important challenges for port management is defining and prioritizing investments [9]. In response to this, regular performance measurement is one of the most important tools to meet this challenge. Thus, the investments can be easily managed according to the demands and trends of the market tracked by regularly monitored port performance.

While ports had been a shelter for ships or a facility that carried out the loading and unloading operations of the ships in the past, they have turned into a living space for all foreign trade stakeholders and a business unit that serve a large number of customers and produce value-added businesses covering almost all logistics services. Therefore, it will be more appropriate to consider the dimensions of port performance as interdependent components, considering today's complex port management [4]. For example, while traditional measurements focus only on the seaward of the port, there is also a need to measure the connection level of the onshore [10]. Many of the studies take into account operational and financial indicators when evaluating port performance [11]. However, evaluating the port performance only in these two dimensions will not be suitable for the complex structure of the ports in terms of the services they provide to ships, cargoes, and other transportation modes [12]. Studies in recent years show that performance measurement has evolved towards focusing on a large number of indicators rather than only financial measurements and focusing on macro-level (national) performance rather than micro-level (organization) or regional-level (industry) performance [13]. Based on this, Onwuegbuchunam [14] argued that new port performance indicators should be developed because of the changing roles of the ports. Objective criteria are required to make a meaningful performance assessment of the world's leading container ports [15]. Accordingly, UNCTAD [16] revealed that port performance has a financial, market (customer) based, human resources, and operational dimensions.

This study aims to review port performance literature and exhibit all dimensions of port performance and its indicators. For this purpose, the whole reached articles that measured ports’ performance or reviewed related measurement tools were researched thoroughly.

Accordingly, in the second section, the methodology of this study and review process were presented, and the review of the literature made in the scope of 'performance measurement', 'internal and external factors that affect port performance', 'milestones in port performance measurement' and results obtained from the detailed review was expressed. In the third section, each indicator of each performance dimension used in the port performance literature was detected. Finally, similar studies taken part in related literature were evaluated and the results of the research were discussed.

2. Methodology

In this study, port performance-related literature was presented by reviewing academic articles issued in academic journals which are available at the 'Google Scholar'. 'Google Scholar' database was selected for review because no different studies were found in other academic databases. So, the search was made by combining the words 'port' and 'performance' in the 'Google Scholar' database considering articles after the year 2000. However, an exemption was made to Tongzon [17] and Martinez-Budria et al. [18], because they were approached as basic articles in terms of its contents. After reading abstract sections of the studies, 124 articles were seemed to be relevant for our research. A frequency analysis method was employed to examine relevant literature. First, a literature table that contains the methods of the accessed articles and the performance dimensions they assessed were revealed, and thus, the articles were classified. Then, homogeneous information obtained after the classification of the articles by dimensions was brought together. In the light of such information, dimensions of the port performance and its indicators were revealed. Besides statistical data related to the contents of the studies were analysed with the help of Microsoft Excel.

2.1. Literature Review

Bichou [19] classified the methods used in port performance assessment into three groups: performance measurements and index methods, economic impact studies, and efficient frontier approaches. Traditionally, port and terminal performance have been assessed by way of calculation of whether optimizing the efficiency of handling operations at the berths and terminal areas [20][21]. However, port performance can also be evaluated via calculation of its technical effectiveness or cost-effectiveness, or comparison of the port's actual output with the targeted output [22]. Herein, the measurement of the desired or expected performance dimension is critical because port performance measurement is an important tool in terms of managing relations with stakeholders and achieving a sustainable competitive position [23]. A performance measurement or metric, however, is presented numerically to quantify one or more attributes of an object, product, process, or any related factor, and should allow comparison and evaluation in contrast with objectives, criteria, and/or historical data [19].

Until the 1980s, performance measurement was mostly limited to financial measurements. Performance measurement techniques emerged through the use of a double-entry accounting system [13]. Over time, operational performance dimensions such as effectiveness, productivity, utilization, and effectiveness, which will enable measurement on an operational scale, have been added to these techniques [24]. However, today, performance measurement techniques are more complex considering the factors such as the more complex business environment, ever-changing global customer behaviour, and developing company structures. In the literature, there are two types of port performance measurement approaches, which are descriptive and empirical. Descriptive approaches provide information to be used to observe long-term data behaviour. On the other hand, empirical models that measure port performance are used to obtain time-series graphs, horizontal section graphs, scatter diagrams to reveal the relationships between two or more variables and the relationships between its trends [25]. At this point, Somensi et al. [26] revealed that Data Envelopment Analysis (DEA) and Multi-Criteria Decision Making (MCDM) methods are frequently employed in port performance measurement studies. In addition to this, from the port selection perspective, there are two basic approaches to the evaluation of port performance. The traditional approach is based on direct measurements involving observations, interviews, surveys, while the behavioural approach focuses on the port users' decisions and measures [27].

However, due to the unique nature of the ports which are highly affected by local dynamics, an internationally accepted standard port performance measurement tool has not been developed yet. Although at the macro level, such performance measurement tools have been developed for the logistics industry. For example, the logistics performance index which is an interchangeable comparison tool, generated to help countries identify the challenges and opportunities in trade logistics, is a measurement tool developed by the World Bank and recognized in the international logistics world [28]. On the other hand, the project called 'PPRISM' put forward by the European Commission is the most concrete study that tried to set the port performance measurement to a standard. After all, this project cannot fully meet the needs due to its problems in terms of digitising performance dimensions [78].

Although port performance is one of the most popular topics in the literature, there is no consensus on which factors affect port performance. While some researchers think that administrative factors have an impact on port performance, some researchers relate between the port performance and management structure, geographic factors, the port's socio-economic environment, or the local supply chain system [29]. Studies that pointed out the importance of the location [30][31][32] emphasized that the ports in different regions perform differently. One of the most important elements in the external environment of the port is the political environment. Some studies [33][34][35] suggested that political decisions determine port performance to some extent. Some studies [31][36] defended that ports should obtain economies of scale by increasing the capacity to improve their performance. At this point, it would not be correct to confine the capacity concept to physical capacity. While expressing the linear relationship of the capacity with port performance, some authors [37][38][39] brought the economic capacity of the port environment into the forefront, some of them [6][40] emphasized information and technology capacity, and one of them [41] pointed out the port's service capacity. Accordingly, many authors think that the factors that determine the quality of the port infrastructure and superstructure, such as length, design, and maintenance of the infrastructure and superstructure, availability, seaside accessibility, etc. affect the performance [33][42][43][44]. On the contrary, Pak et al. [45] advocated the exact opposite and stated that the intangible resources such as recognition, technology knowledge, effective process, and qualified personnel fundamentally affect the port performance.

Performance perceptions of ports have changed as well as the evolution of ports over the years. In this sense, there are milestone articles in the literature thanks to their contributions to the concept of port performance. Tongzon [17] was the first to reveal the determinants of the port performance. Bichou and Gray [10] discussed that exclusively financial and production-based evaluations on port performance remain incapable to determine customer satisfaction levels. Cullinane et al. [7] had one of the unique studies that processed performance inputs and outputs long term and evaluated with panel data analysis. Darbra et al. [53] were first-timers to inject sustainability concerns in the port performance concept. Woo et al. [68] expressed that port performance is versatile, cannot be limited to internal processes, and is linked to external service aspects such as service quality and logistics aspects. Madeira et al. [71] presented the first known study that employed one of the MCDM methods to evaluate the performance of ports. De Langen and Sharypova [78] became the initial researchers who used the 'intermodal link-level' as one of the performance indicators. Li and Jiang [91] presented the first known study that handled the collaboration performance of the ports with its dry ports. Antao et al. [100] approached safety performance as a separate port performance item. Musso and Sciomachen [121] proposed solutions for alleviating mega vessels' effects on port performance.

Today's ports operate as logistics centres and even trade centres as a result of the increasing volume of cargo transported with the spread of trade to all countries. This situation brings competition among the ports in its wake. On the one hand, Cullinane and Wang [46] believed that inter-port competition will encourage ports to improve its performance within the framework of the Orthodox economic theory. On the other hand, Cheon et al. [47] argued that competition increases performance at first, but over time this pressure will exceed a certain threshold and will downgrade performance. As a result of competitiveness pressures such as the increase in ship sizes and the variety of cargoes that can be containerized in recent years, dry ports have been used in container terminals' hinterland. Dry ports, with its additional areas and facilities, shorten waiting times at the port, regulate cargo traffic, provide container segregation and transportation options, so increase the capacity of the port, approximate the ports to its hinterland, ensure that the ports offer services diversity, and enhance the foreign trade capacity of the region by bringing the ports closer to the manufacturer [48]. For this reason, it is expected that dry ports have a positive impact on port performance by increasing their efficiency, the number of ship calls, reliability, and berth productivity. As another way of dealing with this competitive pressure, Han [49] proposed that ports should cooperate with supply chain partners to provide value-added services to their customers. However, ports should cooperate with not only supply chain service providers. Within the port area, customers (consignors, consignees), regulatory groups (freight forwarders, logistics service providers), physical groups (terminal operators), authoriser groups, and financial groups (insurance companies) need to interact with each other horizontally and vertically [50]. In this sense, the management of these relations can directly affect port performance. For this reason, Hervas-Peralta et al. [51] who pointed out the right planning stated that port performance will be increased if the focus is on terminal area optimization. In support of this, Esmer [5] highlighted the internal factors such as handled empty containers, inefficient container movements (displacement movements within the bay), the automation level of the ship to shore cranes, container weight, and the necessities for special requirements as well as commercial constraints.

2.2. Results

As a result of the frequency analysis, information such as the year and the journal in which the articles were published, the methods in which the articles were employed, and the performance dimensions in which the articles revealed while measuring the port performance were classified and shown in Table 1.

Table 1. *Literature Table*

Year	Reference	Journal	Method(s)	Approached Performance Dimension
1995	[17]	Transportation Research Part A	Mathematical model	infrastructure and superstructure, operation, financial
1999	[18]	International Journal of Transport Economics	DEA	financial, operation
2001	[33]	Transportation Research Part A	DEA	operation, financial, infrastructure and superstructure
2002	[42]	Review of Urban & Regional Development Studies	DEA	operation, infrastructure and superstructure
2004	[10]	Maritime Policy & Management	Structured Interview	operation, financial, customer satisfaction
2004	[41]	Maritime Economics & Logistics	DEA	operation, infrastructure and superstructure, financial, customer satisfaction
2004	[7]	The Review of Network Economics	DEA and Panel data analysis	operation, infrastructure and superstructure
2004	[52]	Journal of Marine Science and Technology	Hierarchic score method, Grey relational analysis,	operation, financial, infrastructure and superstructure
2004	[53]	Marine Pollution Bulletin	Literature review	sustainability
2005	[54]	Transportation Research Part A	stochastic frontier analysis	operation, financial, customer satisfaction, infrastructure and superstructure,
2006	[55]	International Journal of Logistics: Research and Applications	DEA	operation, infrastructure and superstructure
2006	[20]	Transportation Research	stochastic frontier analysis and DEA	infrastructure and superstructure, operation
2006	[22]	Research in Transportation Economics	Literature review	financial, operation, safety
2006	[19]	Research in Transportation Economics	Literature review	financial, operation, customer satisfaction
2007	[56]	Applied Mathematics and Computation	Fuzzy MCDM	infrastructure and superstructure, operation, financial
2007	[57]	Research in Transportation Economics	Literature review	operation, infrastructure and superstructure, financial, customer satisfaction, safety
2007	[15]	Maritime Policy & Management	DEA	operation

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***Table 1.** Literature Table (Cont')*

Year	Reference	Journal	Method(s)	Approached Performance Dimension
2008	[58]	Maritime Policy & Management	Literature review	operation, financial, infrastructure and superstructure
2008	[59]	Maritime Policy & Management	Mathematical model	operation
2008	[43]	European Journal of Scientific Research	DEA, Correlation Analysis, Regression Analysis	operation, infrastructure and superstructure
2008	[60]	Transportation Research Part A	Factor Analysis	operation, financial, infrastructure and superstructure, customer satisfaction, logistics
2008	[5]	Dokuz Eylül Üniversitesi Sosyal Bilimler Enstitüsü Dergisi	Literature review	operation, infrastructure and superstructure, financial
2009	[8]	IUP Journal of Infrastructure	Correlation Analysis, Principal Component Analysis	operation, infrastructure and superstructure
2009	[61]	Journal of Cleaner Production	Literature review	sustainability
2009	[32]	Maritime Policy & Management	DEA	operation, infrastructure and superstructure
2010	[34]	Journal of Economic Studies	DEA, Panel data analysis	infrastructure and superstructure, operation
2010	[62]	Maritime Economics & Logistics	DEA	infrastructure and superstructure, operation
2010	[63]	International Journal of Computational Intelligence Systems	DEA	operation
2010	[64]	Transportation Planning and Technology	Free Disposal Hull, DEA	financial
2010	[46]	Operations Research Spectrum	DEA, ANOVA	operation, infrastructure and superstructure
2011	[65]	Analele Universitatii "Eftimie Murgu" Resita Fascicola de Inginerie	Literature review	operation
2011	[66]	Scientific Research and Essays	Fuzzy MCDM	infrastructure and superstructure, operation, financial
2011	[67]	Resources, Conservation and Recycling	Mathematical model, DEA	operation, financial, sustainability
2011	[68]	Maritime Economics & Logistics	Confirmatory Factor Analysis	operation, safety, customer satisfaction, logistics, financial
2011	[69]	Transport Policy	Fuzzy ANP	operation, financial, infrastructure and superstructure

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Table 1. *Literature Table (Cont')*

Year	Reference	Journal	Method(s)	Approached Performance Dimension
2012	[30]	International Journal of Physical Distribution and Logistics Management	T Test	operation, logistics, financial, safety
2012	[70]	Journal of Management & Economics	Depth interview, t Test	safety, operation
2012	[71]	International Journal of Production Economics	Factor analysis, MACBETH	financial, operation
2012	[72]	Simulation Modelling Practice and Theory	Simulation Model	operation, infrastructure and superstructure
2012	[73]	The Asian Journal of Shipping and Logistics	Factor analysis, Fuzzy logic	sustainability
2012	[74]	International Journal of Business Performance Management	DEA	operation, financial, infrastructure and superstructure, customer satisfaction, logistics
2012	[75]	Transport Policy	Literature review	operation
2013	[76]	International Journal of Physical Distribution and Logistics Management	AHP and Fuzzy MCDM	sustainability
2013	[77]	Research in Transportation Business and Management	Mathematical model	sustainability, financial
2013	[78]	Research in Transportation Business and Management	Mathematical model	logistics, operation, sustainability, financial, infrastructure and superstructure
2013	[79]	Research in Transportation Business and Management	Correlation Analysis	operation, safety, logistics
2013	[35]	Research in Transportation Business and Management	Mathematical model	infrastructure and superstructure, operation
2013	[80]	Research in Transportation Business and Management	Stochastic frontier analysis, DEA	operation, infrastructure and superstructure
2013	[81]	Girişimcilik ve Kalkınma Dergisi	Descriptive analysis	financial, customer satisfaction
2013	[82]	Supply Chain Management: An International Journal	Structural equation model	operation, financial, customer satisfaction, logistics
2013	[83]	Maritime Policy & Management	DEA	sustainability, financial, infrastructure and superstructure, operation
2013	[21]	Transport Policy	DEA	operation, infrastructure and superstructure
2013	[84]	Polish Maritime Research	Interview	financial, operation, logistics

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Table 1. Literature Table (Cont')

Year	Reference	Journal	Method(s)	Approached Performance Dimension
2013	[85]	Maritime Economics & Logistics	DEA	infrastructure and superstructure, operation
2014	[12]	Verimlilik Dergisi	DEA	infrastructure and superstructure, operation
2014	[86]	Transport Reviews	Literature review	operation
2014	[87]	İstanbul Üniversitesi İşletme Fakültesi Dergisi	DEA	financial, operation
2014	[88]	Transportation Research Part E	Mathematical model	operation, financial, logistics, safety
2014	[3]	Maritime Policy and Management	Factor analysis	operation, financial
2014	[89]	Decision Support Systems	Mathematical model	operation, financial
2014	[90]	Transportation Research Part A	Hierarchical cluster analysis	operation, infrastructure and superstructure, financial
2014	[91]	International Journal of e-Navigation and Maritime Economy	Grey Relations Analysis, AHP	customer satisfaction, financial, operation
2014	[92]	Marine Pollution Bulletin	Delphi	sustainability, operation
2014	[9]	Maritime Policy & Management	Importance - Performance Analysis	operation, safety, financial, customer satisfaction
2014	[93]	International Journal of Research in Applied, Natural and Social Sciences	Literature review	infrastructure and superstructure, logistics, operation, financial
2015	[94]	Transportation Research Part C	Simulation Model	infrastructure and superstructure, operation
2015	[95]	Transportation Research Procedia	Multiple Regression Analysis	operation
2015	[96]	Alphanumeric Journal	DEA	infrastructure and superstructure, operation, financial
2015	[45]	The Asian Journal of Shipping and Logistics	Fuzzy TOPSIS	operation, safety, customer satisfaction
2015	[13]	International Journal of Logistics Research and Applications	Literature review	operation, financial, customer satisfaction, sustainability
2015	[1]	International Journal of Productivity and Performance Management	Literature review	operation, sustainability, financial, customer satisfaction
2015	[97]	Transportation Research	DEA	infrastructure and superstructure, operation

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Table 1. *Literature Table (Cont')*

Year	Reference	Journal	Method(s)	Approached Performance Dimension
2015	[98]	International Journal of Operations and Logistics Management	ELECTRE	operation, financial, infrastructure and superstructure
2016	[2]	Benchmarking: An International Journal	DEA	operation, financial
2016	[99]	IEEE Transactions on Intelligent Transportation Systems	Mathematical Model	operation
2016	[100]	Safety Science	Literature review	safety, sustainability
2016	[101]	International Journal of Logistics Research and Applications	Structural equation model	logistics, operation, financial
2016	[24]	Transportation Research Part A	Stochastic frontier analysis, DEA	infrastructure and superstructure, operation
2016	[37]	Maritime Policy & Management	Factor analysis, Structural equation model,	sustainability, financial
2017	[26]	Intangible Capital	Literature review, Bibliographical portfolio analysis	logistics, operation, financial
2017	[102]	Maritime Policy and Management	Delphi analysis	sustainability
2017	[103]	The Asian Journal of Shipping and Logistics	AHP and Fuzzy TOPSIS	operation, customer satisfaction
2017	[4]	Transportation Research Part A	AHP, DEMATEL, ANP	operation, financial, customer satisfaction, logistics, sustainability
2017	[104]	Journal of Management, Marketing and Logistics	DEA	operation, infrastructure and superstructure
2017	[11]	Economics and Finance in Indonesia	Hybrid Least square methods	operation, financial
2017	[105]	Maritime Economics and Logistics	Mathematical model and DEA	operation, safety, infrastructure and superstructure
2017	[38]	Forum Scientiae Oeconomia	Literature review	financial, operation
2017	[31]	Maritime Economics and Logistics	Network analysis and Panel Regression	infrastructure and superstructure, operation
2017	[25]	Computer Science	Port Efficiency Performance (PEP) Model	operation
2017	[106]	International Colloquium on Logistics and Supply Chain Management	Principal component analysis	financial, operation, infrastructure and superstructure
2017	[107]	MATEC Web of Conferences	Stochastic Simulation Model	operation

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Table 1. *Literature Table (Cont')*

Year	Reference	Journal	Method(s)	Approached Performance Dimension
2017	[23]	Transportation Research Part E	DEMATEL, ANP, Fuzzy ER	operation, financial, customer satisfaction, logistics, sustainability, safety
2017	[108]	Journal of Management, Marketing and Logistics	TOPSIS	infrastructure and superstructure, operation
2017	[109]	Journal of Business Management		operation, financial
2017	[110]	Marine Pollution Bulletin	Semi-structured interview	sustainability, financial
2017	[47]	Maritime Policy & Management	DEA	sustainability, operation, infrastructure and superstructure
2018	[111]	International Journal of Quality and Reliability Management	Sigma Value (SV), the Process Capability indices (PCIs), and the Cost of Poor Quality (COPQ)	operation, financial, safety
2018	[112]	Journal of ETA Maritime Science	DEA	infrastructure and superstructure, operation
2018	[113]	The IUP Journal of Supply Chain Management	Importance Performance Analysis (IPA), Quality Function Deployment (QFD) and Interpretive Structural Model (ISM)	operation, customer satisfaction
2018	[14]	Logistics	Queue Analysis	operation, logistics, infrastructure and superstructure
2018	[36]	Maritime Economics & Logistics	Meta frontier analysis, DEA, stochastic frontier analysis	operation, infrastructure and superstructure
2018	[114]	Journal of Integrated Coastal Zone Management	Duncan Test	sustainability
2018	[50]	Production and Operations Management Society	Mathematical model	operation
2018	[28]	Jurnal Teknik Industri	AHP	financial, infrastructure and superstructure, operation
2018	[49]	The Asian Journal of Shipping and Logistics	Factor analysis, Regression Analysis	financial, operation, customer satisfaction
2018	[40]	Journal of Shipping and Trade	Correlation Analysis	logistics, operation, financial
2019	[44]	Cogent Business & Management	Structural equation model	infrastructure and superstructure, financial, operation

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Table 1. *Literature Table (Cont')*

Year	Reference	Journal	Method(s)	Approached Performance Dimension
2019	[115]	International Journal of Information Management	Correlation Analysis, Regression Analysis	logistics, operation
2019	[116]	Transportation Research Part D	Literature review	sustainability
2019	[117]	International Conference on Engineering, Applied Sciences and Technology	Regression Analysis	operation, infrastructure and superstructure
2019	[118]	Scientific Bulletin of Naval Academy	Literature review	operation, customer satisfaction, logistics
2019	[119]	Sustainability	Literature review	sustainability
2019	[51]	Sustainability	AHP	operation, financial, customer satisfaction, sustainability
2019	[120]	Cogent Business & Management	Exploratory Factor analysis, One-Way ANOVA	sustainability, safety, financial, operation
2019	[6]	Complexity	Mathematical model	operation, financial, infrastructure and superstructure, logistics, sustainability
2019	[122]	Transport Policy	Importance-Performance analysis	operation, infrastructure and superstructure, customer satisfaction, financial, logistics
2019	[123]	AVRASYA Uluslararası Araştırmalar Dergisi	DEMATEL	sustainability
2019	[124]	Maritime Economics & Logistics	Panel Regression Analysis	financial
2019	[125]	Journal of Yaşar University	AHP-TOPSIS hybrid method	financial, infrastructure and superstructure, operation, safety
2019	[27]	Management Decision	Best-Worst method	financial, infrastructure and superstructure, operation, customer satisfaction, logistics
2019	[48]	Maritime Policy & Management	Exploratory Factor analysis	operation, financial, infrastructure and superstructure, logistics
2020	[39]	ISH Journal of Hydraulic Engineering	Correlation Analysis	operation
2020	[121]	Maritime Economics & Logistics	Discrete event simulation model	operation, financial
2020	[29]	Transport Policy	T test, Multiple Regression Analysis, DEA	operation, customer satisfaction, infrastructure and superstructure

As a result of the frequency analysis, it is seen that 25 articles were published between the years of 1995-2009, 40 articles between the years of 2010-2014, 59 articles between the years of 2015-2020. In the light of this information, 79.8 percent of these articles were published after the year 2010. This situation shows that recently, port performance studies have become a trend again in academic literature and there has been much more attention to it. When looking at the journals in which articles were published, 'Transportation Research' draws attention with 14 articles published on the subject, ‘Maritime Policy & Management' accompanied with 12 articles and 'Maritime Economics & Logistics' followed up them with 9 articles. Besides, these three journals are followed by 'Research in Transportation Business and Management' with 5 articles, 'The Asian Journal of Shipping and Logistics' and 'Transport Policy' with 4 articles.

When we look at the statistical data on the most preferred methods in the articles (shown in Figure 1), it is seen that DEA comes to the forefront. Accordingly, while the number of articles employing DEA is 33, this number corresponds to approximately 27 percent of all articles. While 16 percent of the authors contribute to the port performance literature by producing review papers through a literature review, the number of articles that employed one of the MCDM methods is 15. Besides, while 12 studies measured the port performance by proposing a new mathematical model, 9 articles tried to develop a data collection tool related to port performance. The first study employed MCDM methods published in 2012. So, it is detected that the most frequently used method was MCDM methods after the year 2012. Studies that employed MCDM methods and DEA had made a significant contribution to the port performance concept in terms of monitoring the evolution of port performance indicators over the years. It is very difficult to develop a standard data collection tool to measure port performance due to various reasons such as the unique nature of each port type and constantly changing and evolving customer expectations. Perhaps, for this reason, the number of studies trying to combine all port performance criteria using factor analysis was limited to 9.

Finally, the operational performance of the ports has been determined as the most discussed performance dimension in the articles. The operational dimension

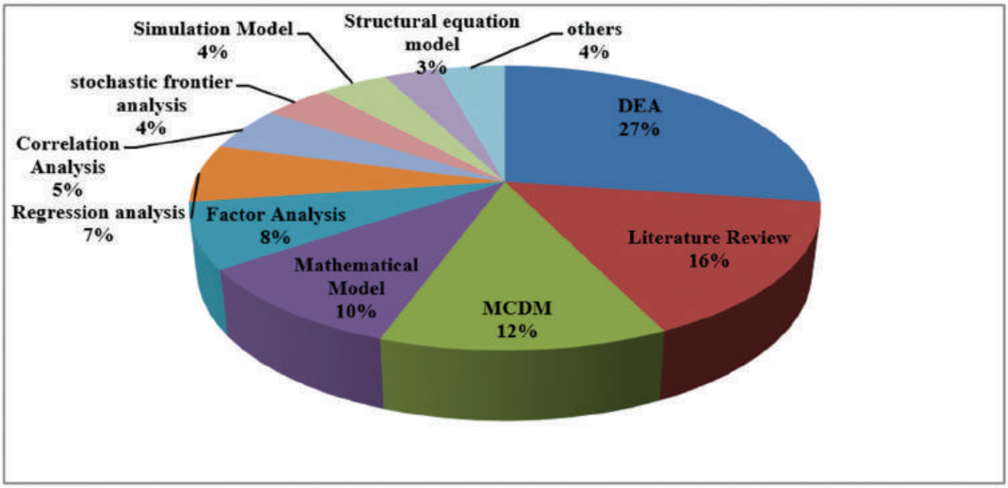

Figure 1. *Employed Methods*

of port performance was approached in 105 different articles, which indicates that this dimension is examined in 86.78 percent of all articles. The financial (economic) dimension of port performance was discussed in 62 studies, and the sustainability dimension, which was trending especially after the year 2010, was handled in 39 studies. Lastly, the logistics dimension of port performance was examined in 22 studies. In the following section, the content of the studies on dimensions of the port performance will be analysed in detail.

3. Dimensions of the Port Performance

In this study contents of the 124 articles were analysed and port performance dimensions discussed in the articles were evaluated. As a result of the frequency analysis employed in this study, it was seen that port performance has operational, financial, sustainability, and logistics dimensions. In this section, indicators of each dimension to provide a measurement tool were presented.

3.1. Operational Indicators

According to Ducruet [126] and Mangan et al. [30], if the parameters of the port performance are constantly monitored, it becomes the standardized parameters of the port operations and these parameter values become the standard of the port [118]. Considering this thought, almost all studies on port performance in the literature either used the operation performance instead of the port performance or integrated an operational indicator into the port performance.

One of the most important indicators of operational performance is the speed concept, especially from a customer perspective. In this sense, Tongzon and Heng [54] and Kavakeb et al. [94] expressed the operational speed level in the ports as an important performance indicator, since the navigational costs of the ships are much lower than the costs during the time they are in the ports. Studies on improving port performance especially emphasize the concepts of efficiency and effectiveness so that port operations can be accelerated [106]. Herein, while traditional port performance indicators focus on specific efficiency criteria, what is expected from contemporary indicators is inclusive of all aspects of the operation and is consistent with the organization's strategies [68]. As almost all the studies analysing the operational performance of ports with DEA did, Lin and Tseng [15] and Ursavaş [89] used the number of calling ships and the loaded and unloaded container volume as outputs, in other words, performance indicators of the DEA model. Esmer [5], in addition to these indicators, approached such the indicators as the rate of the container loaded and unloaded, crane productivity, the automation level of the cranes, average container weight, ship turnaround time, total working time, stored container movement, labour force productivity, area utilization efficiency, equipment usage efficiency, cost-effectiveness. Apart from these, Paing and Prabnasak [117] emphasized that such criteria as 'average waiting time while anchoring', 'average handling cargo tonnage per ship', 'berth occupancy rate', 'container dwell time', 'truck turnaround time' are used as performance indicators in literature. Finally, in the report published by UNCTAD [16], the operation performance of the ports was handled in two different ways: ship operation and cargo operation. Accordingly, while the report handled ship operation indicators with such criteria as "average waiting time (hours), average ship length (meters), average ship draft (meters), average ship gross tonnage"; cargo operation performance was analysed using such indicators as "average tonnage per ship call, cargo tonnage handled per working hour, the number of containers handled per hour, container dwell time (days), handled cargo per area (ton/hectare), handled cargo ton per berth length".

3.2. Financial Indicators

Landlord ports can be influenced by three main factors: competition pressure for infrastructure investment, competition for land use, and financial pressure [109]. To eliminate or at least alleviate financial pressure, ports need to measure financial performance and check compliance with its targets. From a shareholder perspective, port authorities need to increase their net profitability, increase their overall market share, invest in new development projects, and in other words increase their financial performance [109]. The United Nations has accepted financial performance indicators, which measure the extent to which port authority converts capital and funds into performance, as one of the two most important criteria in measuring port performance [11]. The financial and operational performance of port authorities emerges as a result of managerial skills, and the financial performance of a port is of great importance to protect investments and to plan new projects in the future [109].

The financial performance of a port can generally be explained by the profitability of that port. Aguiar-Diaz et al. [124] while measuring the financial performance of Spanish ports, addressed the return of assets (ROA) of the ports as a criterion of performance. On the other hand, Wiegmans and Dekker [2] emphasized that two main indicators determine the financial performance of the ports and that they are sales and profitability. While Muangpan and Suthiwartnarueput [120] considered the unconsolidated financial situation of the port as a financial performance indicator, Roos and Neto [110] took into account financial investment requirement, Bolevics [109] handled net profit, total market share, operating income, total debts, investment intangible fixed assets, Earnings Before Interest Taxes Depreciation and Amortization (EBITDA), Mickiene and Valioniene [38] addressed financial efficiency and financial autonomy, Aqmarina and Achjar [11] approached the rate of return and operating expenses as indicators of financial performance. Brooks and Pallis [58], who handled the financial performance of ports much more comprehensively, included financial indicators such as return on capital employed (ROCE), service revenues, service profitability, trade receivables, interest coverage ratio, terminal charges, ship charges, and these indicators' share in gross income and net profit.

3.3. Sustainable Indicators

While most of the studies related to port management are on the competitiveness or efficiency of the ports, undesirable variables such as CO2 emissions have been ignored in studies on port efficiency [83]. Ports have become a complex system due to factors such as the variety of cargo within them, their location close to the society, and responsibilities for the benefits of their stakeholders. For these reasons and considering today's climate conditions [76], proper management mentality against security and environmental risks within the port area has become very important [100]. To establish harmonious environmental protection and sustainable development, an effective environmental port management strategy needs to consider environmental hazards, mitigation options, forecasting methods, information about environmental indicators, and laws [92]. There are three critical processes to implement environmental management practices at the ports: cooperation with supply chain partners, environmentally friendly operations, and internal management support [67]. Air quality, greenhouse gas emissions, soil and ground resources, rubble, light and sound problems, water, and climate change can be counted among those that need to be improved environmentally to ensure port sustainability. For the economic dimension, indicators such as the benefits of the port users, fair competition, employment, economic development, and tourism and port investment should be taken into account [37]. Environmental performance indicators have tasks such as providing information about environmental problems, supporting development policies and determining priorities, monitoring the effects of policies, pursuing environmental targets, comparing environmental performance over time, and attracting the attention of the society [61]. The social dimension, especially human resources, had been seen as independent variables or input elements. The safety aspect of social sustainability came to the forefront of the literature. The issue of ensuring a safe operation has gained currency lately in the literature and studies conclude that appropriate working conditions have increased labour efficiency and thus the operational performance of the port [100]. For this reason, the safety of the port area has started to be associated with the concepts of effectiveness and competitiveness [68]. Other important results of ensuring safe operation in the port area are the hiring of qualified workers, employing them long-term, and minimizing the economic and social losses of accidents. Recognition of a port as a safe port has a meaning much more for the related unit than business units serving in other industries [45]. Because of the port becomes inoperable due to emerging unsafe situations in the port area, it will have negative results both socially and economically. To take precautions against unsafe situations, it is very important to know what these situations are. Darbra and Casal [127] stated that accidents in ports are mostly occurred during the manoeuvring of the ships, while Yip [128] revealed that most of the accidents in the port area occurred due to the ships crashing into the dock [100]. Unlike, Mollaoğlu et al. [129] grouped the factors that caused the accident in the port area as labour induced, vehicle and equipment induced, facility induced, lack of coordination induced. Accordingly, overconfidence and disengagement behaviour, which are among the labour induced factors, have been identified as the most leading reason for the accidents in the ports.

Lim et al. [116] had not encountered in the literature any studies that are concerned only with the social or economic dimension of sustainability. The general trend in the related literature is that the concepts of sustainable port performance and environmental port performance are interwoven. The first time, Darbra et al. [53] introduced the project, which expresses environmentally friendly practices in the ports, named as the 'Self Diagnosis Method' carried out by ESPO. In this project, criteria such as “air quality, dredging activities, dust management, energy usage, loss of habitat, health and safety management, noise management, soil pollution, waste management and water quality” were used as indicators of sustainable port performance. Saengsupavanich et al. [61] addressed both countable and uncountable criteria such as the number of ISO 14001 Environmental Management System certified facilities and terminals, the number of environmental complaints, the number of fuel/chemical leakage incidents, water quality around the port, penalties imposed on non-observant operators, number of environmental department employees, number of ships inspected annually in the port, environmental expenditures, taxes and allowances, accessibility to the emergency plan, frequency of training, knowledge level of employees on the port state controls, protection of environmental policies, as an indicator of environmental performance. Apart from these, Park and Yeo [73] analysed such indicators as "alternative fuel usage, incentives to reduce pollution, renewable energy usage, development of the breakwater system to revive the dock, resource recycling in the port area, mode change to prevent traffic congestion, artificial sand pile and wetland creation", while they were evaluating the environmental performance of Korean ports. Many new criteria have been added to these sustainable performance indicators over the years: cold ironing (onshore power supply to ships) [76], CO2 emission control [83], odour management [92], water consumption level, and tariff discount to green ships [100], green material usage in the port building process and attending related conferences [37], environmental costs [110], area consumption level [119]. On the other hand, in the social dimension, Antao et al. [100] used such indicators as "the number of off days due to accident, the accident frequency rate, the number of fatal work accidents, the total number of work accidents, the degree of accident severity, the number of absenteeism due to accident or illness, the number of seaward accidents, the number of ships crashes into the dock, the number of near-miss, the number of leakage incidents, the number of fires or explosions" to measure the safety performance of the ports. Brooks [57] handled frequency of accidents, Woo et al. [68] approached compliance with regulations, the number of accidents and the number of prevented accidents, Brooks and Schellinck [79] focused on prejudicial to cargo incidents, Ha et al. [23] used the determination of restricted areas, formal safety training practices, number of adequate observation and threat awareness as indicators that determine whether ports are safe or not.

3.4. Logistics Indicators

For the logistics world, ports are an important nodal point so that they provide intermodal and multimodal transportation services and operate as logistics centres for cargo and passengers [10]. Today, almost all the services provided by logistics companies are expected from the ports by its customers. For that reason alone, ports should cooperate with supply chain partners to provide value-added services to their stakeholders [49]. Among the advantages that a port cooperates with logistics service providers, not only does it increase the value of the relevant port supply chain, but also decreases the value of competing for port supply chains [101]. Through this, many companies are involved in logistics and supply chain integration throughout the port and around the ports [10]. Due to the changing logistics environment, ports should carefully monitor changes and produce strategies accordingly [68].

The logistics performance of the ports is often based on efficiency and utility measurements. Bichou [130] stated that since ports have used their facilities for logistics, production, and economic activities, new port performance indicators are needed [14]. Accordingly, many indicators determine the logistics performance of the ports. These indicators were processed in the academic literature in a way that will differ according to the years, in other words, they were shaped according to the market situation. Bichou and Gray [10] have identified processes such as logistics integration, benchmarking, logistics channel design, value-added services, customer service as indicators of a port's logistics performance. Woo et al. [68] added indicators such as service quality, customer orientation level, auxiliary service prices, intermodal cargoes' waiting and working times, to the literature. Seo et al. [101] used the logistics performance indicators of the ports such as convenience to the port users, safety, and security throughout the hinterland, and reliability. Han [49] considered performance dimensions such as cost performance, quality performance, and responsiveness as indicators of the logistics performance of the ports. Finally, Ha et al. [122] have taken into account the level of intermodal transportation systems and value-added services as an indicator of logistics integrations of container terminals.

4. Discussion

When the literature is analysed, it is seen that some studies have made a literature review regarding the port performance and as a result of their analysis, they brought different perspectives to the port performance concept. These studies were analysed in detail and detached aspects of these studies from our study were revealed. Thus, the originality of this study and its contribution to the literature was tried to be revealed. Langenus and Dooms [13] evaluated 74 articles in literature and drew attention to the gap that is less concern on industry specific ports' performance. And the authors proposed that new developments such as the container revolution, big data analytics, knowledge transparency, which affect port performance, should be assessed. Lim et al. [116] reviewed 21 articles focused on the sustainability performance of ports and proposed that social indicators of port performance should be revealed. In our research, it is determined that 8 social indicators revealed in that study used generally as input or independent variable to assess ports' overall performance. Somensi et al. [26] analysed 37 articles in literature and suggested that it should be evaluated whether port management activities contribute to port performance. Similarly, Vieira et al. [86] advocated that there is a research gap in the relationship between port governance and performance. On the other hand, our research suggested a more descriptive approach for collecting data and measuring port performance. Dutra et al. [1] handled 23 articles and remarked that most of the studies are out of interacting with port managers. Unlike, we think that stakeholders of ports should evaluate service quality they receive and thus, port performance would show up.

No other study focusing on the dimensions of port performance was found among the descriptive studies in the literature. On the other hand, it was observed that the empirical studies did not analyse cases by combining the dimensions of the port performance or by separating the related dimensions. Since performance dimensions were thought to have a natural relationship with each other or no measurement model seems to allow this separation. For instance, Brooks and Schellinck [79] asked customers of US and Canadian ports to evaluate the five-year performance of the most frequent port they work with. While they were evaluating these ports' performance, they did measure operational, safety, and logistics performance, but did not take into account financial and sustainable dimensions. On the other hand, most of studies had used operational indicators to evaluate overall performance of ports [42][7][55][15][43][8][32][72][35][80][21][85][94][95][99][24][25][107][108][36][39][50]. However, the originality of this study comes from this point. Our research suggests that analyses on port performance should be made by separating its dimensions from each other. After this separation, an analysis of the preferred dimension(s) should be carried out.

5. Conclusion

Ports are more than just a meeting point for carriers and shippers today but are the nodes of global trade and produce value-added services for many stakeholders. So, the concept of port performance has changed greatly over the years and the performance perception of each port stakeholder has differed from each other. For example, while operational quality in the terminal area is perceived as a high performance by shippers or carriers, on the other hand, the legislative bodies or local community perceive efficient sustainability applications as high performance or logistics service providers care about hinterland connection quality more. At this point, the perception of the shippers, the port authority, the company that provides towage and pilotage service, etc. can differ from each other. For this reason, it is very difficult to establish a standard performance measurement. Besides, considering the competition between the ports outside the port area, it is also important to know which performance dimension is desired to measure.

In order to overcome the challenges of standardising port performance measurement, different perceptions of the stakeholders should be gathered and obtained an overall score or should be exactly separated from each other. So as a contribution of this study, dimensions of the port performance were revealed to bring a new perception to the port performance concept. Moreover, indicators of each dimension were developed for empirical analyses. Thus, different aspects of port performance will be determined and also assessed. Maybe the contribution level of each aspect to overall performance can be evaluated.

For further studies, it would be appropriate to develop a measurement on in which dimension of the port performance is desired to be examined. Although corporate social responsibility (CSR) in ports had been studied many times before, the effectiveness or efficiency of CSR activities was not analysed in the literature. Thus, performance criteria regarding ports' CSR practices can be developed. Most of the studies assessed the operational performance of the ports had seen human resources as an independent variable or input factor to achieve high performance. However, factors that affect human resource quality can be studied. In this way, in-depth analysis of operational performance can be presented.

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Risk-based Analysis of Pressurized Vessel on LNG Carriers in Harbor

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ABSTRACT

The need to understand the associated risks of pressurized vessels and their consequences onboard ship is imperative. The handling and storage of Liquefied Natural Gas (LNG) mostly result in catastrophic accident with associated consequences. To quantify these consequences in terms of death and degree of burn depends on the tank structures and pressure control mechanism onboard LNG carriers in a harbor. In this research, the result of the potential risks and damage consequences of the LNG fire accident in terms of the degree of burns and fatality is presented. The probability of death, first and second degree of burn injuries are assessed using consequence modelling technique, while the pool fire was modelled using the Boiling Liquid Expanding Vapour Explosion (BLEVE) approach. The result shows that at 30 meters from the flame radius, the probabilities for first-degree burn, second-degree burn, and death decrease, respectively. A sensitivity analysis revealed that at the initial heat flux and closer distance of 5m to 10m from the flame radius at the point of the accident, the death rate, first degree, and second-degree burns increase significantly. Therefore, installing a safety system and best practices that will mitigate these risks to as low as reasonably possible should be incorporated into the system design.

Keywords

LNG Carriers, Risk, Harbor, Fire, Explosion, Accidents.

1. Introduction

The oil and gas industries store large volumes of flammable and hazardous chemicals in tanks, including LNG. Hydrocarbon products are highly volatile. Once there is any fuel-air mixture in or around the storage tank, ignition occurs, which results in a fire and explosion accident. Research has shown that most of these accidents occurred during cleaning, storage, maintenance, anti-rusting, spray-painting, welding, loading, unloading work, etc., [1]. Such exercises have resulted in severe fire and explosion accidents with several global consequences [2, 3]. Other examples where such activities resulted in fire and explosion accidents are the Bayamon oil storage facility fire in Puerto

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Rico [4], and the Indian Oil Corporation Ltd explosion accident [5]. Severe environmental pollutions, casualties and economic losses have resulted from fire and explosion of stored hydrocarbon. This points to how safety-critical hydrocarbon storages are.

Hydrocarbon products, especially the LNG, have a high level of risk of fire and explosion. Therefore, it is imperative to study and analyze the risk and consequences of fire and explosion accidents in LNG stored vessels. This research's main objective is to analyze the risk associated with LNG stored in a pressurized tank in a harbor and evaluate the consequences on the people and environment. A fire accident scenario was considered in the study. The research analysis examined a pool fire case study. Risk and consequence analysis models were adopted to demonstrate the case study to assess the degree of impact or damage of the pressurized vessel's fire and explosion. This enables the prediction of the frequencies of possible accidents and the quantitative assessment of both societal risk and individual risk.

2. Review of Relevant Literature

2.1. Risk Assessment and Methodology

Risk is a phenomenon that measures the impact of a hazardous event on the environment, human or economic loss in terms of the incident likelihood and the magnitude of the injury, damage, or loss [6]. Similarly, risk can be defined in terms of the combination of the probability of a hazardous event and the consequences of occurrence [7]. Risk analysis involves risk estimation, information integration about scenarios from the estimated risk, frequencies of occurrence, and consequences [7].

Risk indices are being used by researchers to correlate the magnitude of the risk on people and facilities. For example, a risk ranking matrix has been used to assess various risk levels regarding harm probability and severity categories. This is presented in the two-dimensional framework for likelihood and consequences [8]. Based on this approach, the risk is characterized by categorizing probabilities and consequences on the matrix axes. Risk effect categorization may be individualized or societal. Individual risk is characterized by the likelihood of an individual death per year from an exposed distance to the source of hazard [6]. It is also essential to evaluate the societal risk of pressurized tank fire and explosion, which defined the probability of death of a group of people exposed to hazardous events [9]. It is quantified based on the number of persons involved in the accident. In multiple causality events (accidents), the frequency distribution is commonly represented on the cumulative frequency versus number of fatalities plot (i.e., the F-N curve) [9].

Societal risk effects are mostly presented using a quantitative approach for the hydrocarbon industries. Vulnerability rate describes the degree of exposed threat, the capability to suffer harm, and the extent to which various social groups are at risk [10]. In their research, Li et al. [11] estimated the individual risk of a natural gas pipeline failure under pressure. The authors proposed the “exposure-sensitivity-resilience” framework to capture the social-ecological indicators of the associated risk of natural gas pipeline hazards. However, to adequately capture the risk indicators, CPS/AICHE [12] provides criteria for individual risk and societal risk estimation due to exposure to adverse/major accidents in the chemical, oil and gas industries. Fire and explosion accident analysis was presented by [1] for oil depots, and the result of the study shows that most of the common accidents are due to the vapor cloud explosion. This accident type and its management should be targeted by minimizing/controlling the predisposing causes. Rigas and Sklavounos [13] investigated various accident scenarios based on real data, using quantitative statistical estimation. Jianhua and Zhenghua [14] analyzed fire and explosion onboard LNG ships. They used the DOW Chemical Exposure Index (CEI) criteria, BLEVE model, and Vapor Cloud Explosion (VCE) model to predict the consequences of fireball without considering the probability of impact on the environment. Also, in [15], the authors present a review of LNG application for ship and land transportation, respectively. They further examined different methods for LNG based analysis, likely accident-prone operations, and the necessary precaution during operation. To further examined the effect of LNG operation, [16] considered the overpressure against the accident's distance of impact and thermal intensity. Therefore, this work seeks to analyze pool fire explosion consequence using the BLEVE model, thermal radiation model, and probabilistic function (probit function) for an LNG carrier at harbor. This will help to reliably evaluate the consequences in terms of burns and death.

3. Methodology

The common modeling algorithm for consequence analysis is shown in Figure 1 [12]. The model estimates the impacts of flammable explosion and release of toxic material due to the loss of containment or system failure on the environment, human, and assets numerically.

Figure 1. *Logic Diagram for Consequence Models due to Releases of Volatile Hazardous Substances [12]*

3.1. Individual and Societal Risk Analysis

To model the individual risk, the likelihood of injury to the individual at the period over which the injury might occur need to be estimated [3]. This is expressed in terms of the exposed likelihood, such as death and is usually quantified as a risk per year [9], as shown by equation (1).

$$\text{Individual risk of exposure (average)} = \frac{\text{Number of fatalities}}{\text{Number of people at risk}} \quad (1)$$

For a geographical location defined by *x,y* within a period, t, the individual exposed risk can be estimated using equation (2) [12]:

$$IR_{x,y} = \sum_{i=1}^{n} IR_{x,y,i} \quad (2)$$

where $IR_{x,y}$ describe the total number of persons at risk (fatality) due to the exposure for a given geographic location, while $IR_{x,y,i}$ is for an individual risk of exposure (fatality) based on the characterized *x, y* geographical location due to a hazard event, *i*. The upper bound n describes the total number of individuals exposed based on the accidental release.

The risk of individual exposure (fatality) due to a hazard event, *i*, $IR_{x,y,i}$, is modeled using equation (3)

$$IR_{x,y,i} = f_i Pf_i \quad (3)$$

where f_i describes the rate of hazard event i, outcome, P_{fi} indicates the likelihood that the hazard event *i,* the outcome will be fatal for the operating *x, y* characterizes geographical location.

The rate *fi* of a hazard event outcome can be estimated by equation (4)

$$f_i = F_i P_{oi}, P_{oci} \quad (4)$$

where F_i describes the rate of occurrence of the hazardous event, with an associated outcome case *i,* while P_{oi}, indicates the likelihood that the hazard event occurs with the associated outcome case, *i*. P_{oci} defines the likelihood of the hazardous event outcome case i occurrence depending on the prior circumstance of the precursor incident *i* and its corresponding outcome case.

For societal risk analysis, the relationship that describes the rate of hazardous exposures and the number of people exposed due to the accidental release need to be established [9]. These two measures are essential for a well-informed risk mitigation/reduction criteria adapted for facility operation assessing the benefits of risk reduction measures or acceptability criteria for risk critical facility. Equation (5) is used to predict societal risk [9]:

$$N_i = \sum_{x,y} P_{x,y} P_{f,i} \quad (5)$$

where N_i describes the outcome of the hazardous event, *i,* (that is the number of fatalities as a result of the hazard event), $P_{x,y}$ indicates the population at the geographical location that the hazardous event occurs, and P_{fi} indicates the likelihood that the hazardous event *i*, the outcome will be fatal for the operating *x, y* characterizes the geographical location.

3.2. Hazard Impact Assessment

The complete risk assessment due to hazardous events involves predicting the fatality likelihood at a given exposure. The fatality likelihood as a result of the exposure death is calculated using Probit Function (see equation (6)) [17]. Effect assessment models are adopted to measure the degree of impact of the exposure. The hazard incident outcome can be due to different factors, as reported by [13].

$$P_r = c_1 + c_2 InD \quad (6)$$

where P_r represents the probit, C_1 is a model constant that is dependent on the type of injury, C_2 is also constant, which depends on the load type. D is the load. A conversion table from probit to percentage was provided by [12]. For different hydrocarbons, the modeling constants c_1, c_2 are provided [12].

3.3. Consequence Assessment

This involves an analytical modeling tool to assess the hazard potential and subsequently translate into potential consequences (e.g., harm to people, pollution to the environment, or damage to the asset). To calculate the number of burns due to exposure or fatality, the thermal dose ought to be quantified. Mathematically, the thermal dose is expressed in term of the exposure time and the heat flux as presented by equation (7) [18]:

$$D = t_{eff}\,(q')^{4/3} \quad (7)$$

q'=calculated heat flux in W/m^2

t_{eff} = the effective exposure time of a person to heat flux in (seconds)

For a fire pool developed in an area where the population is high, that is about 1 person per 20m^2 (in the whole area), the probability of injury (first or second-degree burns) and death in 30m from the flame's surface in terms of the number of the persons with first and second-degree burns, and fatality will be calculated by equation (10).

For the case study, the heat flux will be calculated as $q'=26.964e^{-00238x30}$= 13.2 KW/m^2 for 30m. For U = 4m/s, Xo=138.42m (at 138.4m, q'=1kW/m^2) and r = 30m. The exposure time was calculated as:

$$t_{eff} = t_r + \frac{(x_o - r)}{u} \quad (8)$$

where; t_r = person' s response time in (s)
X_o = is the distance between the flame's surface and the position where the intensity of the heat flux is lower than 1 kW/m^2 in (m)
r = the distance of the person from the surface of the flame in (m)
u = the escape velocity in (m/s)

$$t_{eff} = 5 + \frac{(138.42 - 30)}{4}$$
$$t_{eff} = 32.11s$$

The thermal radiation dose was calculated "as"

$D = 32.11\times(13.204)^{4/3} = 10.02\times10^6\ W^{4/3}\ sm^{-8/3}$

3.3.1. The Probability of Death or Injury

The number of fatalities or injured persons due to exposure could be predicted based on the Probit function. The Probit function is widely employed due to its broad applicability in assessing the risk involved in fire accidents. The probability of death or injury (P), because of a specific thermal dose is given by equation (9):

$$P = F_k \frac{1}{2}\left[1 + \mathrm{erf}\left(\frac{Pr - 5}{\sqrt{2}}\right)\right] \quad (9)$$

4. Results and Discussion

This research assesses the risk involved if a pool fire should occur in an LNG storage tank on an LNG carrier in harbor. A case study data as recorded in [18] was adopted with the following as input parameters: "Boiling temperature, T_b= 423 k; Heat of Combustion, ΔHc = 45,000KJ/Kg; Heat of Vaporization, ΔHv = 370KJ/Kg; Specific heat capacity, CP= 2.21KJ/Kgk. Ambient temperature, T_a = 298 k; Soot surface-emitting power, SEPsoot = 20 KW/m^2; Wind velocity, uw= 5 m/s; Density of air, ρ_{air} = 1.21 Kg/ m^3; Viscosity of air, η_{air}= 16.7μPas, Saturation water vapour pressure, P_w = 2320 P_a; Relative humidity, RH = 0.7"

For this research, *Fk* value of 0.40 was chosen to account for its influence in the probability estimation. The coefficients C_1 and C_2 have values depending on the death and degree of burn. The values of these coefficients can be obtained from Table1.

Table 1. *Coefficients c_1 and c_2 [12]*

Effect	c_1	c_2
1st degree burn	-39.83	3.0186
2nd degree burn	-43.14	3.0186
Deaths	-36.38	2.56

The probit function for the 1st degree burn is given as follows:

$$Pr = -39.83 + 3.0186\ln(10.02\times10^6)$$
$$Pr = 8.83$$

The probability of 1st degree burns at r = 30m is calculated as:

$$P = 0.4 * \frac{1}{2}\left[1 + \mathrm{erf}\left(\frac{8.83 - 5}{\sqrt{2}}\right)\right]$$

$$P = 0.3999$$

The probit function for the 2nd degree burn is given as follows:

$$Pr = -43.14 + 3.0186\ln(10.02\times10^6)$$
$$Pr = 5.5212$$

The probability of 2nd degree burns at r = 30m is calculated as:

$$P = 0.4 * \frac{1}{2}\left[1 + \mathrm{erf}\left(\frac{5.52 - 5}{\sqrt{2}}\right)\right]$$

$$P = 0.2794$$

The probit function for deaths is given as:

$$Pr = -36.38 + 2.56\ln(10.02\times10^6)$$
$$Pr = 4.887$$

The probability of deaths at r = 30m is calculated as:

$$P = 0.4 * \frac{1}{2}\left[1 + \mathrm{erf}\left(\frac{4.887 - 5}{\sqrt{2}}\right)\right]$$

$$P = 0.1822$$

The probabilities of 1st, 2nd degree burns, and deaths are 0.3999, 0.2794, and 0.1822. The predicted impact at varying distance from the center of the flame is shown in Table 2 and Figure 2.

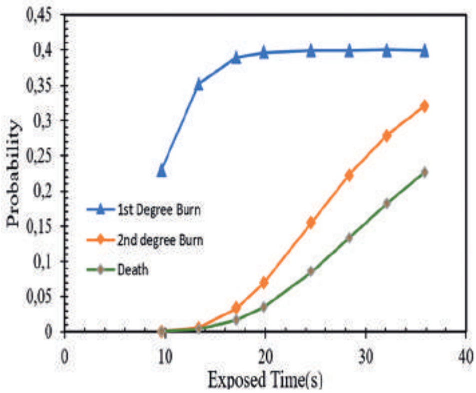

Figure 2. *Predicted Impact at Varying Distance from Center of Flame*

The result shown in Figure 2, gives the probability of impact with respect to the time of exposure to thermal radiation dose during fire accident. It shows that the probability of burn or death increase with the time of exposure. This indicates that as the person's duration of exposure to the thermal radiation dose increases, the likelihood of impact increases accordingly. However, for the 1st degree burn, there is an asymptotic characteristic as the time of exposure increases, as shown.

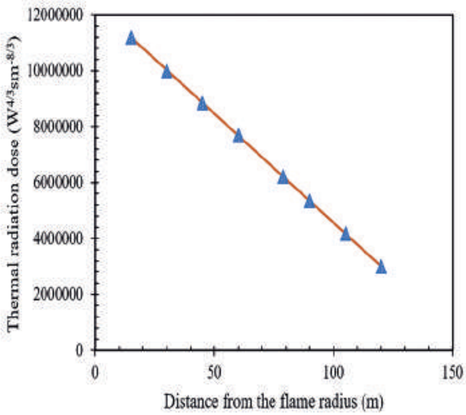

Figure 3. *Thermal Radiation Dose-effect Against Flame Radius Distance*

The result shows that the probability of burn and death increases with the rate of exposure to fire or explosion. This implies that an increase in the exposure time increases the degree of burn on the individual. Also, as the distance from the flame center increases, the probability of impact gradually decreases, as shown in Table 2. Figure 3 shows that the thermal radiation dose-effect decreases correspondingly at the farther distance from the radius of the flame. Hence, critical firework or accident causative factors should be monitored in case of maintenance work.

4.1. The Total Number of Victims in the Pool Fire Accident

Having calculated the probabilities of burns (whether 1st or 2nd degrees), equation (10) is used to calculate the number of victims who died and/or sustained the two degrees of burns, as mentioned.

$$N = (N_o \pi R^2) + \int_R^{\infty} P\, N_o\, 2\pi r dr \qquad (10)$$

N_o - the number of persons/m^2
R - radius of the fire

The first term in the expression used to predict the number of fatality within the fire radius, and the second term (including the corresponding probit function for death) is used to estimate the number of deaths outside the fire flame radius. Calculations of the number of victims who suffered 1^{st} or 2^{nd} degree burns are calculated using the second term (with their appropriate probit functions).

Table 2. *Predicted Probability of Burns and Death at Varying Distances from the Flame and Exposed Hours*

Distance from Flame (m)	Exposed Time (s)	Thermal Radiation Dose ($W^{4/3}$ $sm^{-8/3}$)	Probit 1^{st} degree burn	Probit 2^{nd} degree burn	Probit Death	Probability 1^{st} Degree Burn	Probability 2^{nd} Degree Burn	Probability of Death
15.00	35.85	11183757.33	9.16180	5.85180	5.16873	0.39999	0.32113	0.22680
30.00	32.10	10013908.24	8.82828	5.51828	4.88588	0.39997	0.27915	0.18183
45.00	28.35	8844059.14	8.45328	5.14328	4.56786	0.39989	0.22279	0.13313
60.00	24.60	7674210.05	8.02500	4.71500	4.20464	0.39950	0.15513	0.08528
79.00	19.85	6192401.19	7.37738	4.06738	3.65541	0.39651	0.07020	0.03575
90.00	17.10	5334511.86	6.92723	3.61723	3.27365	0.38921	0.03335	0.01686
105.00	13.35	4164662.77	6.17994	2.86994	2.63989	0.35240	0.00663	0.00365
120.00	9.60	2994813.68	5.18455	1.87455	1.79572	0.22928	0.00036	0.00027

Given that the population density at the terminal is 1 person per $30m^2$, implying that N_o is 0.033 persons/m^2 and the radius of the petrol pool calculated as 21.22m, the number of deaths inside the radius of the fire is calculated as:

$$N = N_o \pi R^2 = 0.033 \times 3.142 \times (21.22)^2$$
$$N = 46.69 \approx 47 \text{ workers}$$

Calculating the number of deaths outside the fire radius and victims with 1st and 2nd degrees of injury requires a probability relation expressed in terms of r, the distance from the flame's surface to the farthest point in the area under consideration (30m). Thus, a general expression for thermal dose D is obtained as follows:

$$D = (3202.4603 + 20.215r)e^{-0.031733r} \quad (11)$$

Appropriate probability expressions are then obtained that incorporate corresponding probit function expressions with appropriate C_1 and C_2 values. The integrals based on equation (10) is used to predict the number of death as shown:

The number of deaths is:

$$N = 0.04147 \int_{21.22}^{\infty} r[1 + erf(-29.26 + 1.810 \ln((3202.4603 + 20.215r)\, e^{-0.031733r}))]\, dr$$

The number of victims who sustained 1st degree burns is:

$$N = 0.04147 \int_{21.22}^{\infty} r[1 + erf(-31.70 + 2.134 \ln((3202.4603 + 20.215r)\, e^{-0.031733r}))]\, dr$$

The number of victims who sustained 2nd degree burns is:

$$N = 0.04147 \int_{21.22}^{\infty} r[1 + erf(-34.04 + 2.134 \ln((3202.4603 + 20.215r)\, e^{-0.031733r}))]\, dr$$

The approximate solutions of the integrals as shown above for the accident scenario, reveals the following:

- 66 personnel will suffer 1st degree burns
- 14 personnel will suffer 2nd degree burns
- 85 deaths (within fire radius, 1st and 2nd degree burns inclusive)

4.2. Risk Estimation

The risk associated with the pool fire accident is calculated as the product of the rate of occurrence of the pool fire and the consequence of the fire on workers at the terminal. Thus, the risk associated with each fire consequence is shown below:

- Risk of victims who sustained 1st degree burn $= 1.9\times10^{-6}\times66 = 1.254 * 10^{-4}$
  $= 0.0001254$ victims/km years
- Risk of victims who sustained 2nd degree burn $= 1.9\times10^{-6}\times14 = 2.66 * 10^{-5}$
  $= 2.66\times 10^{-5}$ victims/km years
- Risk of deaths $= 1.9\times10^{-6}\times85 = 1.615 * 10^{-4}$
  $= 0.0001615$victims / km years

5. Conclusion

The adopted methodology for pool fire analysis is advantageous due to its ability to evaluate the probability of the top event (release rate of LNG in the storage tank based on this case study). The combination of several root causes, such as leaks, overpressure, ignition, spark, and the possible consequences of this release, such as numbers of burns and death, were evaluated. The LNG release rate may be due to different root causes since everyone can lead to the release of LNG. The research conclusively shows that:

- The release rate of 1.712E-02 per 1000km years for the leak was observed.
- The probabilities evaluated for 1st and 2nd degree burns and fatality at 30m from the flame radius were defined by the fire sphere for the case study.
- For the same heat flux, the fire's impact decreases accordingly based on the distance from the fire flame radius.
- The sensitivity analysis (Table 2) shows the predicted save zone from the incident's point by varying the flame radius and the exposure time. This provides a technical guide on the appropriate safety barrier/action needed for safe maintenance operations.
- The number of deaths, first-degree burn, and second-degree burn at the flame radius range of 5-10m decrease respectively with respect to the thermal dose. This indicated that the worker in the harbor within the sphere would suffer the greatest damage (mostly death).

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Weighting Key Factors for Port Congestion by AHP Method

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ABSTRACT

Port congestion is one of the most important factors for measuring port performance and a critical problem that affects seaports' performance, productivity and efficiency levels as well. Determining the most important factors affecting the port congestion in detail contributes to the economic and social growth of the ports. This paper makes an effort to contribute to the existing literature by determining importance weights of factors leading to port congestion as the unique study on the matter. Therefore, it is aimed to identify the most important factors on port congestion according to the port state control, flag state control and independent surveyors' points of views. For this purpose, a literature research was conducted on the factors causing port congestion and experts on the field were consulted. Then the collected data were classified in a list and the determined factors have been ordered with Analytic Hierarchy Process method by experts. The importance weights of the factors have been identified and the most significant factors for port congestion have been obtained with the pairwise comparison of the criteria. According to the results, it can be argued that the most important main factors for port congestion are documentation procedures, port operation and management, ship traffic inputs, port structure and strategy and government relations, respectively.

Keywords

Port Congestion, AHP, Criteria for Port Congestion

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1. Introduction

Commercial shipping is a key factor in international goods transportation, therefore international trade depends on shipping by means of moving cargo from one region to another. For international trade, new shipping demands to accommodate different types of cargoes and new ship designs for a faster long distance freight transport, ensuring a minimum cost per long tonnage. [1]. It is also compatible with the development of seaports for increased rate of international trade and transportation, for efficient loading and unloading of cargo from ships. At this point, ports must be operated efficiently, with enough space to accommodate berths, with modern technological transport equipment and ships, sufficient skilled manpower, efficient handling of documentation process and, storage facilities and good infrastructure [2]. For instance, Tongozo[3] states that the efficiency of a port is crucial for achieving competitive advantages and it is expressed through the provision of good services that are expected by ship owners and customers. According to Nilsson[4], one of the most important factors to consider for measuring port performance is also port congestion.

From this point of view, it can be said that port congestion is a critical problem, which affects seaports' performance, productivity and efficiency levels. It is a fact that ships create congestion at the port entrances by using a lot of time in the channel or during berthing. The ships wait in the anchorage area and line up for berthing to the port. The waiting time is calculated using the service time of the ships. Ships' service time is a way to measure the efficiency of ports. The congestion is a fact that because of the cargoes reach up to quantities that are much more than the port's handling and storage capacity as well as capacity of the allocated space they can be moved.

Various factors that may cause port congestion have been specified by most studies. These are listed in general headings as follows [5]: inefficient and old port infrastructure, inconsistent governments' policies, failure to meet technological trends in globalization and manpower problems of some ports, excessive demand for supply of port services. When the factors that cause port congestion are examined in detail, the following items are encountered[6]:reserving the port or terminal beyond its capacity, industrial actions or strikes, pandemics such as COVID-19, lack of allocated space or stockpile, delays due to bad weather resulting in ships lining up outside, war, limited port access, lack of port handling equipment, slow productivity, hinterland connections and location of the port. Port congestion, caused by a variety of factors may also add some extra costs to the supply chain, such as inventory costs and exorbitant demurrage costs. Jansson and Shneerson[7] stated that the effect of port congestion on economic as follows: 'Congestion costs exist if the other short-run costs of port operations, per unit of throughput, are an increasing function of the actual capacity utilization. When actual demand exceeds capacity, extreme congestion costs arise, which we call queuing costs. When a port is said to be congested, it is commonly meant that ships are queuing, waiting to obtain a berth'.

Considering the effects of the port congestion problem on a port as mentioned above, in order to any port not to encounter with this problem, modern ports must focus on investing in modern equipment and other infrastructures to develop and expand the port area for compensating increased cargo volume of ships. On the other hand, by determining the most important factors via considering the factors affecting the congestion of the port in detail, contributes to the economic and social growth of the ports.

In this context, it is aimed to identify most important factors on congestion of a port, according to the port state control, flag state control, and independent surveyors' points of views. For this purpose, first factors causing port congestion were researched from the literature, experts were consulted and the collected data were classified in a list. Then, the determined factors have been ordered by experts, in accordance with Analytic Hierarchy Process (AHP) method. As part of the scope of this study, experts have been designated as independent, port state and flag state surveyors who have been empowered to carry out various inspections in accordance with national and international conventions and rules for ships approaching ports. By the pairwise comparison of criteria, the importance weights of the factors have been identified via the AHP method and the most significant factors for port congestion have been obtained.

For this purpose, factors causing port congestion were researched from the literature, experts were consulted and the collected data were classified in a list. Therefore, the ports that have port congestion problems gain an insight into which area they should improve and a port investor can also refer to these factors when creating a port project.

2. Literature Review

Congestion of ports, as one of the major reason of disruptions to maritime transport operation networks, results infertility and increase the costs of logistics and trade[2][8].

Although port congestion is defined as "waiting for berthing" in literature, additional concerns are possible when mentioned port congestion by separating as "major categories of congestion". These are; ship berth congestion, ship work congestion, vehicle gate congestion, vehicle work congestion, ship entry/exit route congestion, and additionally cargo stack congestion[5][9].

Considering port selection, both port congestion and distance of navigation are major determinants for shippers[10]. On the other hand, Nilsson [4] states that not only distance of navigation and port congestion but also distance of the shipper from port, distance from origin and to destination and shipping line's fleet size affects shippers' port choice. In another study, Lirn et al [11] examines the transshipment port selection by global carries by AHP method to explore factors affect port selection criteria and advices in strategic perspective to transshipment market.

In the sense of the container ports, continuous growth in container transportation by vessels which puts industry under pressure results with congestions at port land entries and that situation affects port productivity negatively [6][12]. Port productivity in container terminals has direct influence on port efficiency and not only depends on psychical factors but also organizational factors [13].

On the other hand, considering the issue of port congestion, the unique nature of the port, which differs from port to port, should be taken into account [9]. Several studies have been made regarding port congestion both for optimization to increase port efficiency and analysis of policies about increase of psychical structures, capacity and modernization. Oyatoye et al [14] highlight the importance of queuing theory to the port congestion problem to increase the sustainable development of Nigerian ports. The study determines that the number of berths in the port of Nigeria was sufficient for the traffic density of the ships, includes the content analysis of the interview with the stakeholders at the port and other factors that caused port congestion. Also, policy recommendations are made for a cost-effective and more attractive solution that also includes the rapid return of ships in Nigerian port. Maneno [2] evaluates factors affecting port congestion for Port of Dar es Salaam / Tanzania. For that purpose, Maneno makes a literature review and list the factors of port congestion, prepares a questionnaire and makes a survey with stakeholders. In the result, Maneno makes recommendations both psychical and organizational for solution of port congestion problem in Port of Dar es Salaam. In another study, land side congestion of traffic for The Consorzio Napoletano Terminal Containers (CO. NA.TE.CO.), located in the Port of Naples / Italy analyzed with Queuing theory and according to results offer solutions [15]. As an alternative truck chassis exchange terminal to increase truck flow in container terminals [16]. Another optimization study by Jin et al [17] puts another solution alternative to berth congestion problem by column generation based approach to optimize container flow by berth and yard design.

Even if several studies made regarding mitigate port congestion and it's factors by optimization or mathematical methods, the best way for removing port congestion is using modern equipment, expanding terminal size and capacities, which is inevitable for some countries to keep their role upright in maritime transportation, such as Canada [2][18][19]. Besides, for several countries, port congestion is a major problem and needs to be organized both by governments and private sector for best results. Cullinane and Song [20] evaluate The Republic of Korea and showing as an example to developing countries in strategic planning. Potgieter [21] focuses on Cape Town Container Terminal and uses both qualitative and quantitative methods for identification, analyze evaluation and recommendations for mitigation of port congestion factors. Fan et al [22] investigates congestion problem in container terminals of USA with spatial competition and explores the negative results of the consequences. Emecen[23] compares supply and demand in Marmara ports by queuing theory. The study results the current capacity is enough to handle ship flow and gives recommendations in case of increase on demand. Zorlu [24] examines port clutter in Turkey, highlights the importance and magnitude of The Gulf of İzmit area ports and recommends building a big transit port to the area. Yeo et al [25] analyze the effects of vessel traffic conditions in 2011 for Busan and assess the potential for marine traffic congestion using the AWE-SIM simulation program. According to the results, enlarging of the superstructure of the container terminals, the reallocation of terminal functions in number two pier, and the elimination of anchorage are the emergent tasks to minimize possible congestion for Busan. Abu Alhaol et al [26] present three maritime port congestion indicators mined using static and dynamic messages of Automatic Identification System. The considered indicators are time of service criticality, spatial density, and, spatial complexity. They proposed that these indicators can be used by port authorities and other maritime stakeholders to predict for future congestion levels that can be correlated to high demand, weather, or a sudden collapse in capacity due to sabotage, strike, or other disruptive events. Saeed et al [27] explain governance strategies that several players in the maritime field can adopt to decrease port congestion by developing a conceptual model. For examining port congestion decrease from a governance perspective, they use frequency, and uncertainty, asset specificity, and prevail in the maritime sector as three characteristics of transaction cost analysis. According to their study, the main reasons for port congestion are caused by other members of the port supply chain. These factors can be frequency of cargo (mega vessels), and/or environmental uncertainty (for example, trucker strikes, bad weather). Neagoe et al [28] present a paper that highlights "how a supply chain perspective deploying information systems can improve port congestion management by stimulating collaboration amongst multiple transport and terminal operators". They state that one of the reasons of congestion management systems' low solution acceptance because of the trucking industry. This is caused by lack of engagement from the port or terminal operators, inflexible systems to transporters' business demands, and one-sided benefits derived by the terminal from the congestion management systems. Li et al [29] present "a hybrid simulation model that combines traffic-flow modeling and discrete-event simulation for land-side port planning and evaluation of traffic conditions for a number of what-if scenarios". They show that problem of port congestion is resulted from external vehicles traveling in spaces with very limited traffic regulation and complexity of heterogeneous closed-looped internal vehicles and the traffic interactions with port operations such as loading and unloading cargoes. Pruyn et al [30] introduce a study to predict port waiting times for Mormugoa, New Mangalore, Shanghai, and Esperance ports because of congestion by using historical data from 2012 to 2015 in the Markov chain analysis. They state that forecasting the waiting time in a port can enhance the planning and efficiency of the transportation of cargoes.

For summarizing the literature review regarding port congestion, Table 1 is introduced.

The distinctive feature of this paper from the other studies in the literature is the effort to gather all the studies on the port congestion and its factors in detail, specifically to prove which factors are most important on port congestion. In the literature there aren't many studies available that the most important factors on port congestion present via scientific analysis clearly.

3. Methodology

3.1. Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) represents the hierarchical structure of a system and is developed at first for military by Thomas Saaty in 1980 [31]. The hierarchy, which is formed by various levels including decomposition of main goal to a set of class and sub class, and final level, summarizes the factors according to the goal of the system as in Figure 1. The class of the hierarchical structure is named as criteria or attribute and the sub class of the structure is called as sub criteria or sub attribute. If a multi criteria decision making (MCDM) is the point in question, the alternatives take part in the final level of the hierarchical structure. AHP is the popular method as the methodological procedure since it can be easily performed with multiple, objective programming formulations via the interactive solution process. The basis of the method is based on pairwise comparison of criteria and alternatives by the experts [32].

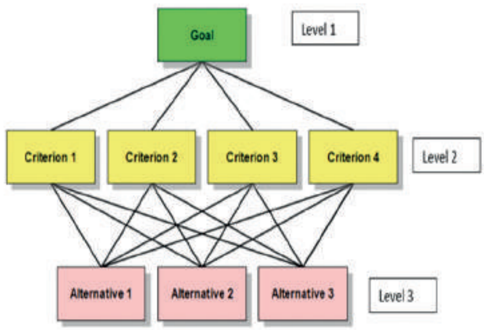

Figure 1. *Sample Hierarchical Structure for AHP*

Table 1. *Summary of Literature Review*

Author	Title of Study	Methodology	The Aim of The Study	Findings or Suggestion
Fadhili HarubuManeno (2019)	Assessment of factors causing port congestion: a case of the port Dar es Salaam	Questionnaires and quantitative methods in data collections Praxeology design	The main purpose of the study is to reveal the factors causing congestion in Dar es Salaamharbor through a survey for investigatingthe challenges faced by port stakeholders and providing solutions to this problem.	The findings of this study showed that Dar es Salaam is faced with various challenges such as documentation procedures, unskilled manpower, poor policy, use of information, communication and information systems, inadequate equipment, bureaucracy, port infrastructure, poor management planning.
Ibeawuchi C. Nze&Chined umOnyemec hi (2018)	Port congestion determinants and impacts on logistics and supply chain network of five African ports	This analytical tool differs slightly from the commonly used queuing theory model, which mostly aims to take into account the arrival and service time of ships and cargoes at ports.	The main purpose of this study is determine the effects of port congestion on Logistics and Supply chain according to some Sub-Saharan African ports.	The findings of the regression analysis reveal that congestion in African ports is entirely due to planning, regulation, capacity, efficiency, or a combination of these.
Usman Gidado (2015)	Consequences of Port Congestion on Logistics and Supply Chain in African Ports	This article examines common port congestion scenarios, their extent, and the various factors that trigger congestion in Lagos, Durban, Mombasa ports.	This article examines the common port congestion scenarios, sizes, and various factors that trigger congestion in the ports of Lagos, Durban, Mombasa and the collection ports of the Suez Canal.	The Durban and Port Said facilities have proved to be the most congestion-resistant ports in Africa, largely due to the robust strategies adopted in the operational distribution of ports and cargo management.
Fırat Bolat& Nil Güler (2015)	Hub port potential of Marmara region in Turkey by network-based modelling	In this study, network-based hub port assessment (NHPA) model is used.	The main purpose of this study is to evaluate whether the port regions of Ambarlı, Gemlik, İstanbul, İzmit and Tekirdağ have the potential to become a main port using the NHPA model.	As a result of the increase in container handling, increases in activity and economies of scale were reflected in the connectivity index. As a result of the instant and active use of this port, the connectivity index has increased and the collaborative index has decreased.
TC Lirn, HA Thanopoulou, MJ Beynon & AKC Beresford (2004)	An Application of AHP on Transhipment Port Selection: A Global Perspective	Approach An Analytic Hierarchy Process (AHP)	This study examines the dominant factors influencing shippers' port selection decisions using Analytical Hierarchy Process (AHP).	The results of the AHP analysis revealed that both global container carriers and port service providers have similar perception of the service features are the most important for transfer port selection.
HarieshManaadiar (2020)	Port Congestion – causes, consequences and impact on global trade	-	In this study, it is aimed to examine the Port Congestion - its causes, consequences and its impact on global trade.	Globalization has led to containerization, leading to an increase in global container trade, which has grown by an average of 9.5% since the 1980s. Between 2000-2018, the global container port business volume increased by 254%.

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Table 1. *Summary of Literature Review (Cont')*

Author	Title of Study	Methodology	The Aim of The Study	Findings or Suggestion
Chang Qian Guan (2009)	Analysis of marine container terminal gate congestion, truck waiting cost, and system optimization	1) data analysis 2) field observations, 3) development of the queuing model, 4) model validation and verification, 5) synthetic analysis, 6) sensitivity analysis, and 7) gate congestion mitigation alternatives.	The aim of this thesis is to analyze the MCT door system study to measure the economic costs of the gate congestion and develop a model to measure, provide alternatives to optimize door operation and reduce the gate congestion in New York Harbor is to investigate the alternatives.	This study provides a comprehensive analysis of this issue, including measuring the cost of congestion and offers several alternatives to reduce congestion.
E.OOyatoye S.O.Adebiyi, J.COkoyeeB.B Amole, (2011)	Application of queueing theory to port congestion problem in Nigeria	The queue model has been applied to the arrival and service model that causes congestion problems and provides solutions to problem areas.	This article aims to examine the problem of port congestion with queuing theory in order to increase the sustainable development of Nigerian ports.	It is recommended that concessionaires at the ports be authorized to start extensive infrastructure development and capacity building.
I. M. Veloqui, M. M. Turias, M. J. Cerbán, G. GonzálezBuiza, and J. Beltrán (2014)	Simulating the Landside Congestion in a Container Terminal. The Experience of the Port of Naples (Italy)	A queuing model has been developed to analyze the congestion problem.	This study aims to examine the reasons why Consorzio Napoletano Terminal Containers (CO.NA.TE.CO.) in the Port of Naples are constantly subject to traffic congestion.	The study shows that the solution must take into account the reduction in service time at the access gate and in the field simultaneously.
Samuel Monday Nyema (2014)	Factors influencing container terminals efficiency: a case study of mombasa entry port	Data Envelopment Analysis (DEA) application has been used in the port industry to measure port efficiency and performance.	The main purpose of the study is to evaluate the factors affecting the efficiency of container terminals in the Maritime industry with the case study of Mombasa Port of Entry in the Republic of Kenya.	More research should be done in the following areas: Maritime Freight Transport Logistics Container Terminals Container Security Policy Implementation and Role of Global Supply Chain Security.
R. Dekker, S. Van Der Heide, E. Van Asperen, and P. Ypsilantis (2013)	A chassis exchange terminal to reduce truck congestion at container terminals	The typical operation of a container terminal and the CET @ solution are outlined, and their effects are measured in terms of both cost, environmental and efficiency.	In this article, a chassis exchanges terminal concept to reduce congestion is presented and analyzed.	Because there is no real handling bottleneck, it also removes the uncertainty of retrieving containers, allowing trucking companies to schedule multiple trips from customers to CET each day.
R. Dekker, S. Van Der Heide, E. Van Asperen, and P. Ypsilantis (2013)	A chassis exchange terminal to reduce truck congestion at container terminals	The typical operation of a container terminal and the CET @ solution are outlined, and their effects are measured in terms of both cost, environmental and efficiency.	In this article, a chassis exchanges terminal concept to reduce congestion is presented and analyzed.	Because there is no real handling bottleneck, it also removes the uncertainty of retrieving containers, allowing trucking companies to schedule multiple trips from customers to CET each day.

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Table 1. *Summary of Literature Review (Cont')*

Author	Title of Study	Methodology	The Aim of The Study	Findings or Suggestion
J. G. Jin, D. H. Lee, and H. Hu (2015)	Tactical berth and yard template design at container transshipment terminals: A column generation-based approach	A set spanning formulation has been developed for the berth and yard template design problem. Column-based heuristics are developed and evaluated with computational experiments.	This article addresses the problem of berthing congestion by presenting a proactive management strategy from a terminal perspective that adjusts ships' calling schedule so that it can balance the distribution of workload on the dock side.	Computational experiments on real-world test samples have demonstrated the efficiency and effectiveness of the proposed approach.
G. Y. Ke, K. W. Li, and K. W. Hipel (2012)	An integrated multiple criteria preference ranking approach to the Canadian west coast port congestion conflict	In the study, a holistic conflict analysis approach that includes the Analytical Hierarchy Process (AHP) based preference ranking method in the Conflict Resolution Graph Model (GMCR) was used.	This article explores the port congestion dispute on Canada's west coast.	The strategic analysis carried out in this research suggests possible decisions that Canada will expand its port facilities in various locations and encourage traders to continue choosing Canada's west coast as one of the trading gateways to North America.
M. Mollaoğlu, U. Bucak, and H. Demirel (2019)	A Quantitative Analysis of the Factors That May Cause Occupational Accidents at Ports	The Fuzzy Analytical Hierarchy Process (FAHP) method	The purpose of this study is to determine the risks that cause Occupational Health and Safety (OHS) violations in the port area and to reveal the prominent risks as a result of expert examinations.	This study is the basis for further studies to be carried out to unify the process of seeing work accidents in the port area.
K. Cullinane and D. W. Song (2006)	Container terminals in South Korea: problems and panaceas	Data Envelopment Analysis or Frontier Production models.	This article examines the extent of the congestion in Korean ports, particularly Pusan, the country's largest port; and new port development programs aimed at attracting private and foreign funding.	From this analysis, a strategy for port development in developing countries can be drawn.
L. Potgieter (2016)	Risk profile of port congestion: cape town container terminal case study	The bow tie method, which is the most common method, is used for this study.	In this study, the timing effect and frequency of the sea side and land side port congestion experienced at the Cape Town Container Terminal to develop the basic risk profiles of current and future port congestion.	Port tailbacks outside the landside congestion and in 2015 proposed to include the effect of further research should be done about truck ban.
L. Fan, W. W. Wilson, and B. Dahl (2012)	Congestion, port expansion and spatial competition for US container imports	An intermodal network flow model was developed and used to analyze congestion in the logistics system for container import.	The purpose of this article, spatial competition of container imports to the United States, is to analyze the congestion and flow.	The findings and results of this study led to recommendations for further research and recommendations for the Port of Cape Town, the shipping industry as a whole.

The purpose of the AHP is aimed to assign weights to tested factors with assessment of experts. Through this method, weights are assigned to factors to serve two important purposes. First, the factors are prioritized or ranked by way of AHP, hence the key factors are identified. It helps to develop key measures oriented the goal, especially in terms of commercial enterprises. Second, by focusing on key measures, the business decision is given more accurate, the key information for commercial operations is determined more correct, or the alternative marketing strategies are evaluated more accurate [33].

The steps of AHP that is used for this paper are shown in the flow diagram as in Figure 2 [34].

3.2. AHP Method for Port Congestion

In this study, the AHP method is used for determining key elements that affect the port congestion, for taking the precaution toward this problem, and for developing new strategies in the matter of port congestion for port investment. In order to identify the most important factors for port congestion, the AHP is most appropriate method. Since, it can assign the weights to the factors that cause port congestion via pairwise comparison between them by the experts. The function of AHP is practical for these goals.

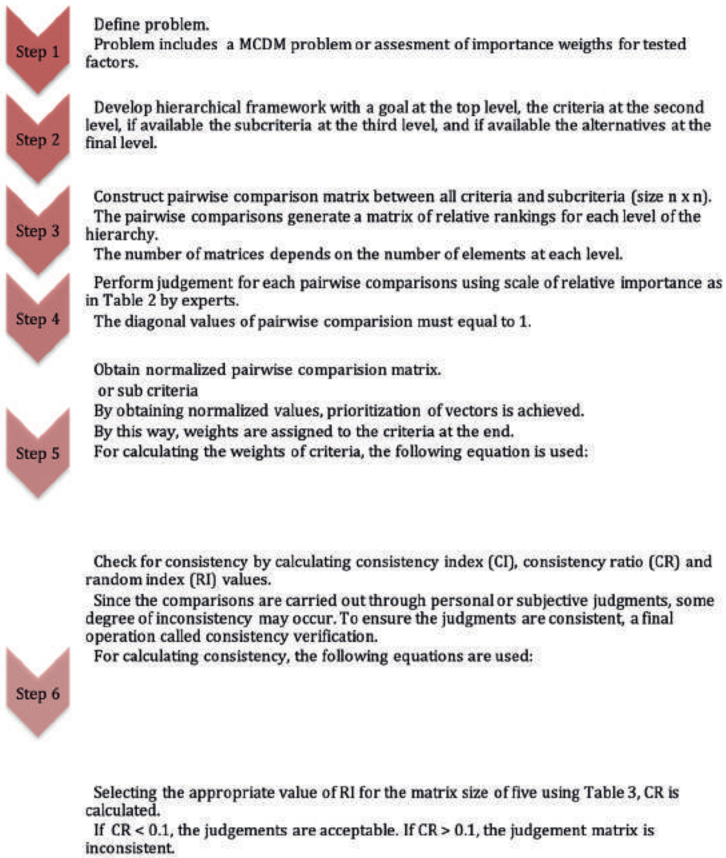

Figure 2. *Flow Diagram for AHP*

Table 2. *Saaty's Scale for Pairwise Comparisons [31]*

Relative Intensity	Definition	Explanation
1	Equal value	Two requirements are of equal value
3	Slightly more value	Experience slightly favors one requirement over another
5	Essential or strong value	Experience strongly favors one requirement over another
7	Very strong value	A requirement is strongly favored and its dominance is demonstrated in practice
9	Extreme value	The evidence favoring one over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgments	When compromise is needed
1/3, 1/5, 1/7, 1/9	Reciprocals	Reciprocals for inverse comparison

3.2.1. Data Collection

According to AHP, for making pairwise comparison, first, experts should be identified clearly. In this study, ten experts including port state control surveyors, flag state control surveyors and independent surveyors are consulted in order to obtain a scoring the criteria according to the scale of AHP. The inspection of foreign ships in national ports is carried out by port state control surveyors. They verify the condition of the ship, its equipment and manned and operated the ship appropriately according to the requirements of international regulations [35]. The flag state control surveyors inspect the vessels registered under its flag, due to their responsibility and authority on the topic of issuance of safety and pollution prevention document and certification. The independent surveyors take part in almost every stage of cargo operation of ship in port such as draft survey, on-off hire condition survey, preloading-discharging survey, super cargo, tally survey, bunker survey and have to be in ports throughout the entire process. All experts have several experiences to carry out various inspections in accordance with national and international conventions and rules for ships approaching ports. For this reason, port state control, flag state control surveyors, and independent surveyors are the most suitable experts to consult to get the most accurate data to identify the most important factors affecting port congestion.

Secondly, an AHP survey is prepared for determining the most important factors on port congestion. The survey for port congestion includes pairwise comparison between criteria and sub-criteria stated in Table 4.

Table 3. *Random Index for AHP*

Size of matrix (n)	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.58

Table 4. *Criteria and Sub Criteria for Port Congestion*

Criteria	Number	Sub criteria
Documentation Procedures	D1	Lack of information and communication technologies
	D2	Customs and port operations
	D3	Lack of influence of owner or charterer
	D4	Deficiencies in the supply program
Ship Traffic Inputs	G1	Waiting for other ships with ship dock occupation
	G2	The delays in multimodal transportation
	G3	Regional intensity
	G4	Accidents
	G5	Delays in arrival-departure
Port Structure	L1	Inadequate load capacity of the port
	L2	Inadequate number of docks at the port
	L3	Inadequate capacity and type of cargo handling equipment
	L4	Insufficient dry-dock capacity
	L5	Insufficient dock depths and tidal effect
Port Operation and Management	Y1	Weakness in the port administration
	Y2	Inadequate port personnel/ not qualified
	Y3	Inadequate number of port staff and subcontractor workers
	Y4	Low port dependency-cooperation index
	Y5	Inefficient working time of the port and poor operating speed
Strategy and Government Policies	S1	Inadequate public-private collaboration and planning
	S2	War-embargo situations
	S3	Inadequate immigration police procedure and security policy
	S4	Strike-lockout status
	S5	Inadequate fight against pandemic
	S6	Inadequate port modernization and not construction of new ports

3.2.2. Application of AHP

Step 1 – Defining the problem

The research question or the problem is determining which are the most significant factors for port congestion. As mentioned in the literature and introduction section, some studies indicated the factors that cause port congestion, but there is no study that reveals the order of importance among these factors. For this reason, this study aimed determining key elements that affect the port congestion, taking the precaution toward this problem, and developing new strategies in the matter of port congestion for port investment.

Step 2 – Hierarchical structure

The hierarchical structure in Figure 3 is established to determine what the most important factors for port congestion are. The criteria and sub-criteria in Figure 3 is obtained from previous studies on port congestion mentioned in the introduction and literature sections.

Step 3 – Pairwise comparison matrix

By comparing the sub-criteria belonging to the same group and main criteria, data is obtained from the experts as in Table 5 and aggregated with arithmetic mean to see the common idea.

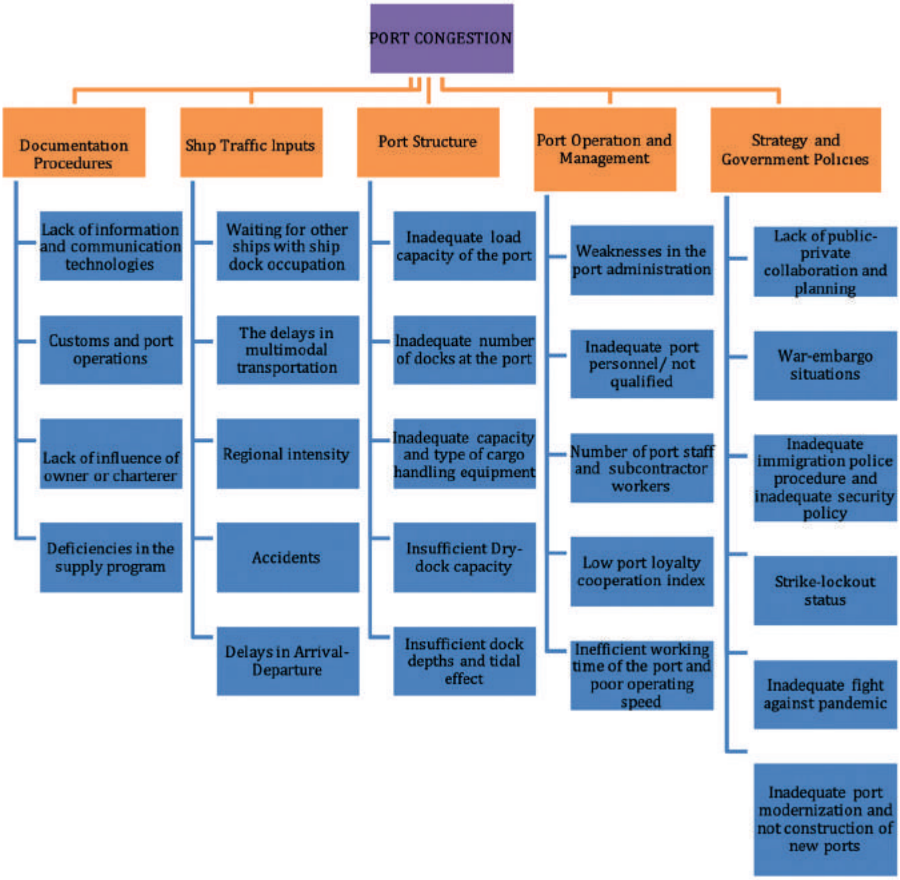

Figure 3. *Hierarchical Structure for Port Congestion*

Table 5. *Pairwise Comparison Matrix and Data from Experts*

Criteria	Compared Factors	EXP 1	EXP 2	EXP 3	EXP 4	EXP 5	EXP 6	EXP 7	EXP 8	EXP 9	EXP 10	Average
documentation procedures (D matrix)	D1/D2	0,25	0,14	5,00	0,50	0,13	0,20	0,20	0,17	0,14	0,33	0,71
	D1/D3	1,00	0,20	0,50	3,00	0,33	0,17	0,25	2,00	0,14	5,00	1,26
	D1/D4	5,00	0,33	4,00	3,00	0,20	0,50	0,33	0,33	2,00	3,00	1,87
	D2/D3	0,20	7,00	3,00	4,00	0,33	2,00	5,00	4,00	0,20	4,00	2,97
	D2/D4	6,00	5,00	0,50	0,25	0,20	2,00	6,00	0,50	1,00	6,00	2,75
	D3/D4	6,00	5,00	4,00	0,25	3,00	5,00	3,00	0,25	0,17	0,20	2,69

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***Table 5.** Pairwise Comparison Matrix and Data from Experts (Cont')*

Criteria	Compared Factors	EXP 1	EXP 2	EXP 3	EXP 4	EXP 5	EXP 6	EXP 7	EXP 8	EXP 9	EXP 10	Average
ship traffic inputs (G matrix)	G1/G2	0,20	5,00	3,00	0,33	0,13	1,00	0,17	4,00	0,25	3,00	1,71
	G1/G3	3,00	3,00	2,00	0,20	0,14	0,20	0,17	0,20	5,00	1,00	1,49
	G1/G4	1,00	0,33	1,00	1,00	0,50	4,00	2,00	0,25	1,00	8,00	1,91
	G1/G5	0,33	0,33	2,00	0,33	0,50	4,00	0,50	0,33	8,00	1,00	1,73
	G2/G3	0,33	0,20	2,00	0,33	0,14	0,14	0,33	3,00	6,00	1,00	1,35
	G2/G4	1,00	0,20	0,33	0,33	0,50	0,50	0,25	3,00	1,00	8,00	1,51
	G2/G5	6,00	0,33	0,33	0,25	0,50	0,33	0,25	0,33	7,00	0,25	1,56
	G3/G4	1,00	0,20	0,50	1,00	7,00	6,00	5,00	3,00	6,00	8,00	3,77
	G3/G5	0,50	0,20	3,00	1,00	7,00	6,00	6,00	3,00	5,00	1,00	3,27
	G4/G5	0,50	5,00	5,00	3,00	2,00	2,00	3,00	0,33	7,00	0,13	2,80
port structure (L matrix)	L1/L2	0,25	0,33	4,00	1,00	0,13	1,00	3,00	0,33	1,00	0,50	1,15
	L1/L3	6,00	1,00	0,20	0,50	0,13	5,00	3,00	=1/4	1,00	2,00	2,09
	L1/L4	1,00	9,00	3,00	2,00	0,13	1,00	0,33	2,00	8,00	1,00	2,75
	L1/L5	5,00	0,20	2,00	0,33	0,13	7,00	4,00	3,00	7,00	5,00	3,37
	L2/L3	5,00	3,00	0,33	1,00	0,25	0,33	4	0,33	6,00	3,00	2,14
	L2/L4	2,00	9,00	2,00	2,00	0,33	4,00	=1/4	3,00	7,00	3,00	3,59
	L2/L5	7,00	1,00	0,17	0,33	1,00	4,00	5,00	0,50	7,00	5,00	3,10
	L3/L4	0,25	9,00	4,00	1,00	4,00	3	0,25	3,00	7,00	4,00	3,61
	L3/L5	1,00	0,33	0,20	0,50	4,00	6,00	5,00	2,00	6,00	5,00	3,00
	L4/L5	4,00	0,11	3,00	0,50	3,00	2,00	5,00	1,00	8,00	1,00	2,76
port operation and management (Y matrix)	Y1/Y2	1,00	0,14	0,25	2,00	5,00	0,13	0,33	0,33	6,00	2,00	1,72
	Y1/Y3	2,00	0,14	3,00	2,00	0,11	0,17	4	0,20	7,00	3,00	1,96
	Y1/Y4	0,50	0,14	0,33	1,00	3,00	1,00	4	3,00	5,00	3,00	1,89
	Y1/Y5	0,25	0,14	0,50	0,33	0,14	0,25	5,00	3	6,00	2,00	1,62
	Y2/Y3	2,00	1,00	0,33	1,00	2,00	4,00	0,20	3,00	0,20	1,00	1,47
	Y2/Y4	3,00	1,00	0,25	1,00	2,00	4,00	0,20	3,00	0,20	3,00	1,77
	Y2/Y5	0,50	1,00	0,25	0,33	2,00	6,00	0,20	0,33	0,17	3,00	1,38
	Y3/Y4	0,33	1,00	0,20	3,00	0,33	1	0,25	3,00	5,00	4,00	1,90
	Y3/Y5	0,25	1,00	0,17	1,00	0,14	0,50	3,00	0,33	6,00	3,00	1,54
	Y4/Y5	0,20	1,00	0,25	1,00	3,00	0,50	3,00	2,00	0,13	1,00	1,21

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***Table 5.** Pairwise Comparison Matrix and Data from Experts (Cont')*

Criteria	Compared Factors	EXP 1	EXP 2	EXP 3	EXP 4	EXP 5	EXP 6	EXP 7	EXP 8	EXP 9	EXP 10	Average
strategy and government policies (S matrix)	S1/S2	2,00	0,11	0,50	2,00	1,00	0,11	5,00	4,00	0,14	1,00	1,59
	S1/S3	4,00	0,14	0,25	2,00	0,33	0,33	6,00	4,00	0,17	4,00	2,12
	S1/S4	9,00	0,14	0,33	1,00	1,00	0,33	5,00	4,00	0,14	4,00	2,50
	S1/S5	5,00	0,14	0,33	1,00	1,00	0,33	6,00	3,00	0,17	8,00	2,50
	S1/S6	0,33	0,14	0,50	1,00	0,17	0,25	5,00	4,00	0,14	1,00	1,25
	S2/S3	0,20	9,00	0,33	2,00	0,33	9,00	0,50	1,00	5,00	0,50	2,79
	S2/S4	1,00	9,00	0,17	2,00	1,00	9,00	1,00	1,00	6,00	0,50	3,07
	S2/S5	0,50	9,00	0,33	2,00	1,00	9,00	0,25	0,25	6,00	0,33	2,87
	S2/S6	0,20	9,00	3,00	2,00	1,00	9,00	0,25	0,33	6,00	0,20	3,10
	S3/S4	1,00	0,20	0,25	0,50	3,00	1,00	2,00	1,00	5,00	4,00	1,80
	S3/S5	0,50	0,20	1,00	0,50	3,00	1,00	1,00	1,00	0,20	4,00	1,24
	S3/S6	0,17	0,20	2,00	0,50	3,00	0,25	0,33	1,00	0,17	1,00	0,86
	S4/S5	1,00	5,00	0,20	2,00	1,00	1,00	0,20	0,33	5,00	0,33	1,61
	S4/S6	0,17	5,00	0,33	2,00	1,00	0,25	0,25	1,00	0,20	0,17	1,04
	S5/S6	0,50	0,14	0,25	1,00	1,00	0,25	0,25	3,00	5,00	0,17	1,16
main factors (A matrix)	A1/A2	1,00	0,33	0,20	0,50	3,00	2,00	6,00	4,00	0,17	5,00	2,22
	A1/A3	5,00	0,33	0,17	1,00	0,25	3,00	5	5,00	0,14	3,00	1,99
	A1/A4	4,00	0,33	0,25	0,50	0,17	0,25	7,00	5,00	0,14	1,00	1,86
	A1/A5	4,00	0,33	0,50	0,50	3,00	1,00	0,14	5,00	0,17	1,00	1,56
	A2/A3	2,00	0,14	2,00	0,50	5,00	0,50	5,00	0,25	0,14	0,33	1,59
	A2/A4	5,00	0,14	0,25	0,50	5,00	0,14	0,20	0,25	0,14	0,25	1,19
	A2/A5	5,00	0,14	0,14	2,00	0,25	0,50	0,14	0,33	0,13	0,25	0,89
	A3/A4	1,00	0,20	1,00	0,50	0,17	0,33	0,17	4,00	0,17	1,00	0,85
	A3/A5	3,00	3,00	0,33	2,00	4,00	5,00	0,17	0,33	0,13	0,50	1,85
	A4/A5	3,00	5,00	2,00	2,00	6,00	6,00	0,14	3,00	0,17	1,00	2,83

Step 4 – Performing judgment of pairwise comparison

Pairwise comparisons of entire sub-criteria are as in Table 6, and the values in the same column are summed up to prepare for the normalization process in step 5 and indicated on the bottom line.

Step 5 – Weights of criteria

To obtain weights of criteria, firstly, all values in pairwise comparison matrix belonging to sub criteria and main criteria are normalized. For normalizing the values, each value in the same column is divided by the sum of the values in that column as shown in Step 5 in the flow diagram. Then, Criteria weights (wi) of the sub criteria and main criteria are obtained by using equation in Step 5 in the flow diagram. Finally, to make consistency analysis in Step 6, Di and Ei values are found according to equation in Step 6 in the flow diagram. The results of all these steps for each criteria and sub criteria are given in the Table 7.

Table 6. *Pairwise Comparisons of Entire Sub-Criteria and Main Criteria*

D matrix	D1	D2	D3	D4
D1	1,00	0,71	1,26	1,87
D2	1,41	1,00	2,97	2,75
D3	0,79	0,34	1,00	2,69
D4	0,53	0,36	0,37	1,00
SUM	3,736860856	2,410337	5,6017472	8,31

G matrix	G1	G2	G3	G4	G5
G1	1,00	1,71	1,49	1,91	1,73
G2	0,58	1,00	1,35	1,51	1,56
G3	0,67	0,74	1,00	3,77	3,27
G4	0,52	0,66	0,27	1,00	2,80
G5	0,58	0,64	0,31	0,36	1,00
SUM	3,357531153	4,754018	4,4110624	8,547143	10,36
L matrix	**L1**	**L2**	**L3**	**L4**	**L5**
L1	1,00	1,15	2,09	2,75	3,37
L2	0,87	1,00	2,14	3,59	3,10
L3	0,48	0,47	1,00	3,61	3,00
L4	0,36	0,28	0,28	1,00	2,76
L5	0,30	0,32	0,33	0,36	1,00
SUM	3,008406386	3,218422	5,8403416	11,31232	13,23
Y matrix	**Y1**	**Y2**	**Y3**	**Y4**	**Y5**
Y1	1,00	1,72	1,96	1,89	1,62
Y2	0,58	1,00	1,47	1,77	1,38
Y3	0,51	0,68	1,00	1,90	1,54
Y4	0,53	0,56	0,53	1,00	1,21
Y5	0,62	0,72	0,65	0,83	1,00
SUM	3,23798391	4,689882	5,6056664	7,386446	6,75

S matrix	S1	S2	S3	S4	S5	S6
S1	1,00	1,59	2,12	2,50	2,50	1,25
S2	0,63	1,00	2,79	3,07	2,87	3,10
S3	0,47	0,36	1,00	1,80	1,24	0,86

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Table 6. *Pairwise Comparisons of Entire Sub-Criteria and Main Criteria (Cont')*

S matrix	S1	S2	S3	S4	S5	S6
S4	0,40	0,33	0,56	1,00	1,61	1,04
S5	0,40	0,35	0,81	0,62	1,00	1,16
S6	0,80	0,32	1,16	0,96	0,86	1,00
SUM	3,70	3,945169	8,4347979	9,952656	10,08207	8,41

A matrix	A1	A2	A3	A4	A5
A1	1,00	2,22	1,99	1,86	1,56
A2	0,45	1,00	1,59	1,19	0,89
A3	0,50	0,63	1,00	0,85	1,85
A4	0,54	0,84	1,18	1,00	2,83
A5	0,64	1,12	0,54	0,35	1,00
SUM	3,13	5,81	6,30	5,25	8,13

Table 7. *Normalized Pairwise Comparisons and Criteria Weights of the Entire Sub-Criteria and Main Criteria*

D matrix	D1	D2	D3	D4	Criteria Weights (wi)	Dİ=∑wi*aij	Ei=wi/Dİ
D1	0,27	0,29	0,22	0,23	0,25	1,04	4,11
D2	0,38	0,41	0,53	0,33	0,41	1,73	4,20
D3	0,21	0,14	0,18	0,32	0,21	0,88	4,11
D4	0,14	0,15	0,07	0,12	0,12	0,49	4,04
SUM	1	1	1	1			

G matrix	G1	G2	G3	G4	G5	Criteria Weights (wi)	Dİ=∑wi*aij	Ei=wi / Dİ
G1	0,30	0,36	0,34	0,22	0,17	0,28	1,49	5,36
G2	0,17	0,21	0,31	0,18	0,15	0,20	1,11	5,46
G3	0,20	0,16	0,23	0,44	0,32	0,27	1,50	5,60
G4	0,16	0,14	0,06	0,12	0,27	0,15	0,79	5,30
G5	0,17	0,13	0,07	0,04	0,10	0,10	0,53	5,14
SUM	1	1	1	1	1			

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Table 7. *Normalized Pairwise Comparisons and Criteria Weights of the Entire Sub-Criteria and Main Criteria (Cont')*

L matrix	L1	L2	L3	L4	L5	Criteria Weights (wi)	Dİ=∑wi*aij	Ei=wi /Dİ
L1	0,33	0,36	0,36	0,24	0,25	0,31	1,63	5,29
L2	0,29	0,31	0,37	0,32	0,23	0,30	1,63	5,37
L3	0,16	0,15	0,17	0,32	0,23	0,20	1,11	5,44
L4	0,12	0,09	0,05	0,09	0,21	0,11	0,56	5,12
L5	0,10	0,10	0,06	0,03	0,08	0,07	0,37	5,09
SUM	1	1	1	1	1			
Y matrix	**Y1**	**Y2**	**Y3**	**Y4**	**Y5**	**Criteria Weights (wi)**	**Dİ=∑wi*aij**	**Ei=wi /Dİ**
Y1	0,31	0,37	0,35	0,26	0,24	0,30	1,56	5,12
Y2	0,18	0,21	0,26	0,24	0,20	0,22	1,12	5,12
Y3	0,16	0,15	0,18	0,26	0,23	0,19	0,98	5,09
Y4	0,16	0,12	0,09	0,14	0,18	0,14	0,70	5,05
Y5	0,19	0,15	0,12	0,11	0,15	0,14	0,73	5,07
SUM	1	1	1	1	1			

S matrix	S1	S2	S3	S4	S5	S6	Criteria Weights (wi)	Dİ=∑wi*aij	Ei=wi / Dİ
S1	0,27	0,40	0,25	0,25	0,25	0,15	0,26	1,65	6,28
S2	0,17	0,25	0,33	0,31	0,28	0,37	0,29	1,79	6,25
S3	0,13	0,09	0,12	0,18	0,12	0,10	0,12	0,77	6,22
S4	0,11	0,08	0,07	0,10	0,16	0,12	0,11	0,66	6,18
S5	0,11	0,09	0,10	0,06	0,10	0,14	0,10	0,61	6,20
S6	0,22	0,08	0,14	0,10	0,09	0,12	0,12	0,76	6,16
SUM	1	1	1	1	1	1			

A matrix	A1	A2	A3	A4	A5	Criteria Weights (wi)	Dİ=∑wi*aij	Ei=wi /Dİ
A1	0,32	0,38	0,32	0,35	0,19	0,31	1,64	5,24
A2	0,14	0,17	0,25	0,23	0,11	0,18	0,95	5,25
A3	0,16	0,11	0,16	0,16	0,23	0,16	0,86	5,27
A4	0,17	0,14	0,19	0,19	0,35	0,21	1,10	5,29
A5	0,20	0,19	0,09	0,07	0,12	0,13	0,70	5,19
SUM	1	1	1	1	1			

Step 6 – Consistency verification

In order to identify the most important factors for port congestion, after the data is received from the experts, it is checked whether these data are consistent or not. For this purpose, in the consistency analysis, the values of max, consistency index (CI), consistency ratio (CR) and random index (RI) are calculated according to equations in step 6 in the flow diagram. The results of the consistency analysis for each matrix are shown in Table 8. According to analysis, if CR< 0,10, the result is consistent.

Table 8. *Results of Consistency Analysis*

Matrices	λmax	CI	RI	CR
D matrix	4,11	0,04	0,9	0,04
G matrix	5,37	0,09	1,12	0,08
L matrix	5,36	0,07	1,12	0,06
Y matrix	5,09	0,02	1,12	0,02
S matrix	6,22	0,04	1,24	0,03
A matrix	5,25	0,06	1,12	0,06

3.2.3. Findings

According to consistency analysis, the results of all pair wise comparisons are consistent and from the result of the consistency, it is understood to valid to specify the order of importance of factors for port congestion. Examining the Table 7, it is seen that the most important main factor for port congestions is documentation procedures (A1). The order of important main factor for port congestion is as port operation and management (A4), ship traffic inputs (A2), port structure (A3) and strategy and government relations (A5), respectively.

In the Table 7, it is understood that the most important factor among the sub-factors of documentation procedures for port congestion is the procedures in port and customs operations (D2). This is followed by the lack of information and communication technologies (D1), the lack of influence of the ship owner or charterer (D3) and the deficiencies in the supply program (D4).

According to results, the weakness in the port administration (Y1) is the most important factor among the sub-factors of port operation and management for port congestion. Then, the lack of qualified port personnel (Y2) and insufficient number of port personnel (Y3) follow it, while the low port loyalty cooperation index (Y4) and the inefficient working time of the port and inadequate operating speed (Y5) are in the last rank with the same criteria weights.

In addition, the most important factor among the sub-factors of ship traffic inputs for port congestion is the waiting for other ships with ship dock occupation (G1). Regional density (G3), delays in connections in multi-model transportation (G2), accidents (G4) and delays in arrival-departure (G5) come after it.

When Table 7 is examined, it is understood that the most important factor among the port structure sub-factors for port congestion is the inadequate load capacity of the port (L1). This is followed by insufficient number of docks (L2) at the port, insufficient capacity and type (L3) of cargo handling equipment, insufficient dry-dock capacity (L4) and insufficient dock depths and tidal effect (L5).

Finally, the most important factors among the sub-factors of strategy and state policy for port congestion are war and embargo situations (S2). This is followed by insufficient public-private cooperation and planning (S1), while insufficient immigration police procedure and insufficient security policy (S3), and insufficient port modernization and new constructions (S6) share third order. The strike-lockout situation (S4) and insufficient outbreak (S5) are in the last two places, respectively.

4. Conslusion

In this study, it is aimed to identify most important factors on congestion of a port according to point of view of the port state control surveyors, flag state surveyors, and independent surveyors. For this purpose, the factors affecting the port congestion obtained from the literature are ordered according to criteria weights using the AHP method.

According to results, it is observed that the main factors for port congestion with the highest importance are documentation procedures, port operation and management, ship traffic inputs, port structure and strategy and government relations, respectively. The most important sub factors are the procedures in port and customs operations, weakness in the port administration, the waiting for other ships with ship dock occupation, inadequate load capacity of the port, and War and embargo situations. When the waiting for other ships with ship dock occupation and inadequate load capacity of the port are considered as one of the important sub factors for port congestion, in this context, by building new hub and sub ports regional density can be reduced, with both port dependency and integrity dock occupation and inadequate capacity of number of docks problems can be solved or as much as possible minimized. Examining the port operation and management in detail, which is one of the important main factor for port congestion, the research findings indicated that the weakness in the port administration is most important sub factor in this category. Taking this factor into account, by investigating the foreign ports' best management practices in terms of operation and management, qualified and sufficiently quantified personnel in port for both management and operational departments can be obtained by a combination of sufficient salary, tax relief and encouragement. In this way, can make an action for the topic of port congestion in the sense of port operation and management. On the other hand, via strategy and governmental relations take place in the end point to affect port congestion, with public-private partnership, a strategic planning can be developed for preventing port congestion efficiently. And finally, new technologies (radio-label-scan) can be integrated to the system to establish digital customization systems (e-manifest, e-bl, etc.) to minimize human factors in the official part of the sector, minimize time spend and to minimize errors, by means of automation.

This paper makes an effort to contribute to the existing literature by determining importance weights of factors leading to port congestion as the unique study on the matter. Therefore, the ports that have port congestion problems may gain an insight into which areas they should develop and a port investor can also refer to these factors when creating a new port project. For further studies, it is considered that grey relational analysis can be practiced for ranking order of some ports taking place in the specific area in accordance with port congestion. For example, five ports can be analyzed in the İstanbul port area or in any other port area and they can be used as alternative for the grey relational analysis. Since, the weighting of the factors effecting port congestion has been obtained from this research, in the further study, real data regarding these factors of the determined ports is obtained. After grey analysis, determined ports are ranked according to the level of port congestion which they have. In this way, the map of port congestion for determined port area may be obtained.

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Simulation-Based Optimization of the Sea Trial on Ships

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ABSTRACT

As well known, ships which have complex production processes are subject to various tests made on every stage in many fields from the beginning to the end of the production. After the tests are completed successfully, the ship is delivered to the ship-owner. "Sea trial" being the last stage of these tests, is examined in detail in this study. The purpose of this study is to plan the tests performed in the sea trial by the means of computer programs and to suggest shorter completion period for the tests. Thus, reducing the total cost of the cruising. Moreover, shortening the duration of the cruise will be a factor that can speed up the delivery of the ship. For this purpose, the tests and processes performed during the sea trial are listed. A cruise process flow diagram including all the tests applied under normal conditions was created, and the data were entered into the SIMIO simulation program. As a result, it was determined that the total cruising time was 28,0989 hours. After that, a new flow diagram was created by making some improvements in the current testing process, and a new simulation model was built up. In the new simulation model, total time spent to complete the tests were 25,3567 hours, so the testing time was shortened by 2.75 (9,76%) hours.

Keywords

Sea Trial, Shipbuilding, SIMIO, Simulation, Optimization.

1. Introduction

Ships are marine vehicles that are manufactured at very high costs in shipyards and have complex production processes. A shipyard must manage the complex processes successfully and deliver the ship to the ship-owner on time. During the construction phase of a ship in the shipyard, many variables consisting of different main topics, such as the correct placement of production lines, the selection of the right equipment, the qualifications of the workers, the experience of the engineering staff, and the selection of an appropriate subcontractors, directly affect the performance and the efficiency of the shipyard, and therefore the punctuality of the delivery. The shipbuilding contracts must be made consciously and freely by the parties, as in every contract [1]. Since

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the delivery time of the ship depends on the agreement between the shipowner and the shipyard, there will be financial losses on both parties in the event of any delays on the delivery dates. Moreover, delay of the ship's delivery due to shipyard may cause negative business consequences for the future of the shipyard.

Given the quality standards and delivery times of the manufactured ships, the general situation of shipyards has paramount importance. With the rapid developments in computer technology and the successful use of these developments in ship engineering, computer simulation methods based on mathematical models have become effective [2]. Depending on the progress of these methods, it is also possible to shorten the delivery times of the ship because ship production considerably varies technologically. Thus, the use of simulation programs in the shipyards allows us to foresee the possible problems, do planning in different scenarios for production and tests.

Ship production is a process that must be continuously monitored and supervised from the beginning of the project phase. In this process, beginning with the tests done on the equipment manufactured in factories, various tests must be carried out within certain rules during each production phase in the shipyards. These tests need to be passed incrementally. It is necessary to check if the ship formed through various stages during the construction period meets the necessary requirements in several points such as safety, maneuverability, equipment, and sufficiency. For this purpose, however, experiences differ throughout the cruise. The International Maritime Organization (IMO) states that it is imperative to perform rotational, zigzag, and stop maneuvers to determine if 100-meter large ships have sufficient maneuverability [3]. Since these tests and experiments conducted in the shipyards are carried out under the supervision of the ship representatives and the class, they assist future crew members of the ship to get familiarised.

2. Literature Research

Thanks to today's technology, simulation programs are used in every field of the industry to see the possible problems that may emerge in the system or working order and to move the production to better levels. Simulation is widely used, especially in the areas where production is continuous and automation-related, such as transportation, medical services, and supply chain.

Ponsignon and Mönch [4] studied factories that had complex manufacturing. By creating production planning based on simulation, they evaluated them with a scenario. It was found out that the simulation could produce stable plans. Medeiros et al. [5] developed models of plate processing operations in terms of the modernization of the plate production line by making simulation-based work on ship-building yard manufacturing process. Caprace et al. [6] developed a simulation on manufacturing processes such as block erection in the shipyard using optimization techniques. It was observed that the choice of a correct mounting sequence had a positive contribution on the production lead time. Another simulation study was carried out by Roh and Lee [7]. In this study, using the 3D CAD method, a suitable simulation method was developed for block mounting for the whole-body structure of the ship. By using the 3D CAM model, the block division method was created, and it was seen that the block mounting was simulated appropriately in the initial design phase. Yuguang [8] proposed the Petri network to make a good block assembly model in shipbuilding industry. He showed that he could contribute to normal planning processes by developing algorithms during assembly with the Petri net model he used. Lamb et al. [9] investigated the validity of theoretical approaches and models using international competitive shipyard production data in their work to improve the shipbuilding process. They defined the shipbuilding process as a result of long studies and modellings. In their work, Cheng and Hongxiang [10] concluded that by simulating the anchorage operation of the ship with the help of Visual C ++, the results obtained can help the staff working on the deck as an exercise.

Abdel-atif et al. [2], by using Simulink software, made use of hydrodynamic forces and moments based on modular mathematics to simulate the maneuver behavior of the Esso Osaka tanker class ship. They also tested the rotation and zig-zag motion and achieved successful results. Cha et al. [11] applied the simulation study that they proposed in the ship and offshore structures to the block assembly process in their study. As a result, they concluded that the simulation work would be useful in this framework, and the development area could be provided. Nam et al. [12] have emphasized the importance of using the simulation at the shipyard in their study. They also tried to create a common structure that would facilitate simulation at shipyards, claiming that it would be a customized simulation for each shipyard. Cha et al. [13], in another study, simulated the block assembly process, which was carried out with a floating crane, by taking the 6 degrees of freedom movements into consideration. Thus, it can be deduced that the resonance frequency can be predicted by simulation, and the situation that may cause danger can be detected in the early stage. Shin and Sohn [14] developed an automated production system for product flow control at a workplace by using objective information technologies such as modeling and networking, emphasizing the importance of the automated shipbuilding process. In this way, product flow simulation was carried out and the problems on the process were evaluated. Ljubenkov et al. [15], have emphasized the importance of using simulation in the shipbuilding production process in their work. It has been seen that the shipbuilding with a complicated production process can be identified with the simulation method, and the parts which may create bottlenecks and problems can be determined. Kim et al. [16] analyzed the simulation of the manufacturing systems in the shipyard in their study. By designing the block erection simulation, they produced a model. Lee et al. [17] dwelled on the panel ship, which was an important part of the shipbuilding production process in their study. The simulation model was verified using a real manufacturing scenario, and the relationship between the model and the panel line was accepted. Hadjina [18] conducted a simulation-based study on the profile cutting line for the shipbuilding process. Vik et al. [19] aimed to get the best production line by using different scenarios in the design phase of a cement plant with SIMIO program. Mandalaki and Manesis [20] made 3D simulations of vessels, vehicles, and human activities for the Patras city port they created in three dimensions with the help of the AutoCAD program. The 3D simulation done with SIMIO aims to examine the changes planned in advance and look for ways to work more effectively in the port with different scenarios. Özkök [21] studied with SIMIO program in his study, and he made the simulation model by making the process analysis of the profile processing unit in the shipyard, and he applied different scenarios to increase the amount of profile production. He concluded that the improvements that can be made on marking and cutting activities can contribute to increasing the amount of profile production. Jeong et al. [22] developed a process-oriented simulation model to simulate the behavior of shipyard logistics. With this simulation, the physical movement of each transaction was analyzed, and a logistic indicator was used for the process. Du et al. [23], in another study, proposed a new simulation-based spatial planning program to avoid the spatial layout problem of the blocks. In this way, visual results for the block layout and process diagram were easily obtained. Lee at al. [24], parallel to new production technologies, worked on a simulation-based shipbuilding planning case. They used a process-oriented simulation technique with the help of a new scheduling system for shipbuilding planning processes. By applying the proposed simulation-based planning system to a real shipbuilding process, it was proven that the quality of production planning could be increased. Ju et al. [25] investigated the mid-term production planning process in the shipyard in detail. Later, they developed a system that can simulate a new discrete event by applying a backward process-centered simulation to this process. The verification of the system was carried out with the production data of four different ships.

3. Material and Method

Simulation technology is used in many production areas. It should be known that in today's world, where the competitive environment is constantly increasing, businesses that aim to survive and achieve continuity in production should improve themselves with the help of simulation and similar techniques. Timely delivery of projects and customer satisfaction are very important for the continuity of the business. In this study, which we think will contribute to the delivery process of the ship, the tests to be carried out during the trial course of a ship whose factory acceptance and harbor acceptance tests have been completed are examined with the help of the SIMIO program, which is based on bottleneck and queue theory, and it is foreseen to reduce the total time spent on the cruise. In this context, the 7-step process shown in Figure 1 has been followed.

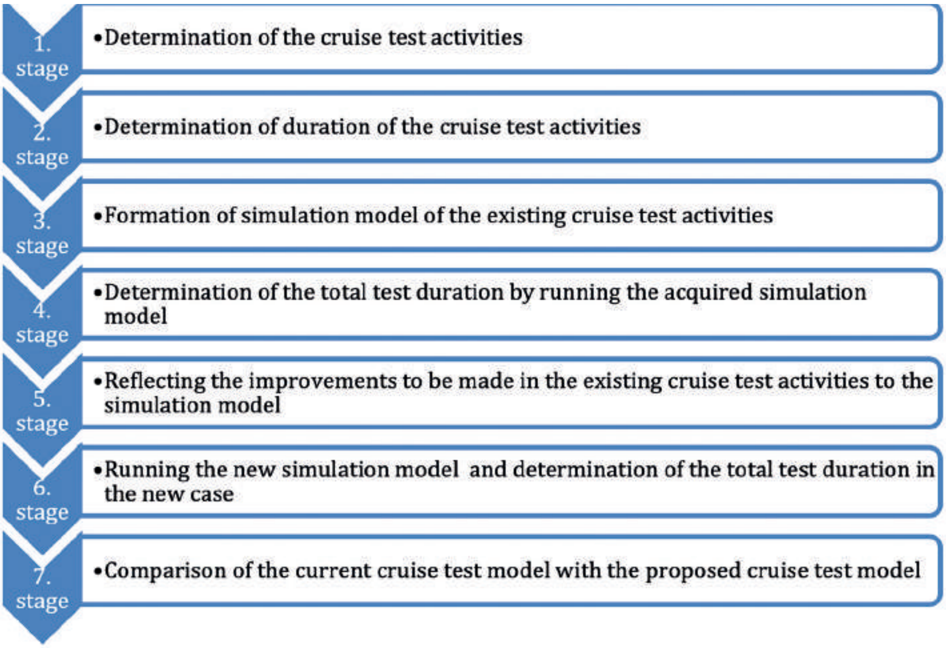

Figure 1. *The Process of Obtaining the Simulation Models of the Tests*

- In stage 1, all the test activities to be carried out on the cruise are identified and listed in a tabular form.
- In stage 2, the durations of the tests to be entered into the SIMIO program are indicated in accordance with the triangular distribution.
- In stage 3, a simulation model of the cruising program, which is available and used in sea trials, has been formed.
- In stage 4, the simulation model has been run, and how long the total duration of the cruise would be under the specified conditions has been stated.
- In stage 5, improvements have been made on the order and sequence of the tests to be done on the cruise, and a new simulation model has been formed.
- In stage 6, a new simulation model has been run, and how long the total duration of the cruise would be in this case has been observed.
- In the 7th stage, the simulation model obtained from the existing cruise test program and the new simulation model obtained after the improvements are compared.

3.1. Cruise Acceptance Tests and Determination of Duration

The ship is ready for cruise acceptance tests after the completion of harbor acceptance tests (HAT) and preparations made before the sea trial. For this study, a cruising program of 8400 DWT chemical tanker was used. Tests and controls planned to be made during the sea trial are given in Table 1. Besides, the application times of the tests and controls corresponds to the data recorded during the sea trial of the 8400 DWT chemical tanker. While preparing Table 1, no order of testing has been applied. Then, using the data in Table 1, a normal workflow diagram of the sea trial has been composed. Afterwards, in terms of shortening the total spend time in the sea trial, a new diagram is obtained by performing the improvement work on the cruise workflow diagram formed before.

Table 1. *Tests and Controls to be Carried Out During the Sea Trial*

Test no	"Tests and controls	Periods (minute)		
		Optimistic	Expected	Pessimistic
1	Going abroad of relevant persons (shipyard, service, class etc.)	45	60	90
2	Startup meeting (shipyard, ship-owner, class)	20	30	45
3	Measurement of ship drafts (fore, stern, midship)	15	20	30
4	Gyro compass settings	45	60	75
5	Boiler controls and alarm tests	30	45	60
6	Bow thruster test – starboard side	20	30	40
7	Bow thruster test – port side	20	30	40
8	Transition from MDO to HFO	15	20	30
9	Booster module tests and its alarms	20	30	45
10	Separator test and its alarms	20	30	45
11	Navigation equipment test	20	30	45
12	Main engine settings	45	60	90

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Table 1. *Tests and Controls to be Carried Out During the Sea Trial (Cont')*

Test no	Tests and controls	Periods (minute)		
		Optimistic	Expected	Pessimistic
13	Freshwater generator test	30	45	60
14	Anchor and windlass test starboard side	20	30	40
15	Anchor and windlass test port side	20	30	40
16	Double bumps steering test	10	15	20
17	Single bump steering test	10	15	25
18	Single bump steering test	10	15	25
19	Port side turning circle test	20	30	45
20	Starboard turning circle test	20	30	45
21	Zig-zag maneuvering test (10°/10°)	20	30	45
22	Zig-zag maneuvering test (20°/20°)	20	30	45
23	Speed test	30	45	60
24	Stopping test	20	30	45
25	Noise measurement test	45	60	90
26	Astern trial	20	30	45
27	Crash stop test	20	30	45
28	Automatic slow down alarms/shut down test	30	45	60
29	Blackout test	20	30	45
30	Main engine endurance test	240	270	300
31	Smoke detection test	45	60	75
32	Automation test (AUT-UMS)	360	400	460
33	Shaft generator control before AVM-APS	15	20	30
34	Alternative drive system test (AVM-APS)	60	75	90
35	Result meeting (shipyard, ship-owner, class)	20	30	45
36	Transition from HFO to MDO	15	20	30
37	Getting back to the shipyard building	45	60	90

The following can be stated regarding the sea trial and Table 1:

- While the duration of each test to be performed in the sea trial was being determined, the preparation phase prior to the test was included to the duration.
- Air and sea conditions are suitable for cruising.
- It is assumed that there is no breakdown on the ship from the start to the end of the sea trial.
- In Table 1, the periods of the tests to be entered into the SIMIO program have been determined as appropriate to the triangular distribution.

3.2. Creating the Simulation Model of the Sea Trial

In Table 1, a sea trial workflow diagram has been created to use in the SIMIO program for the sea trial program, which is composed of 37 items (Figure 2). While this flow diagram was being formed, no improvement work was done on the sea trial program which was performed under normal conditions.

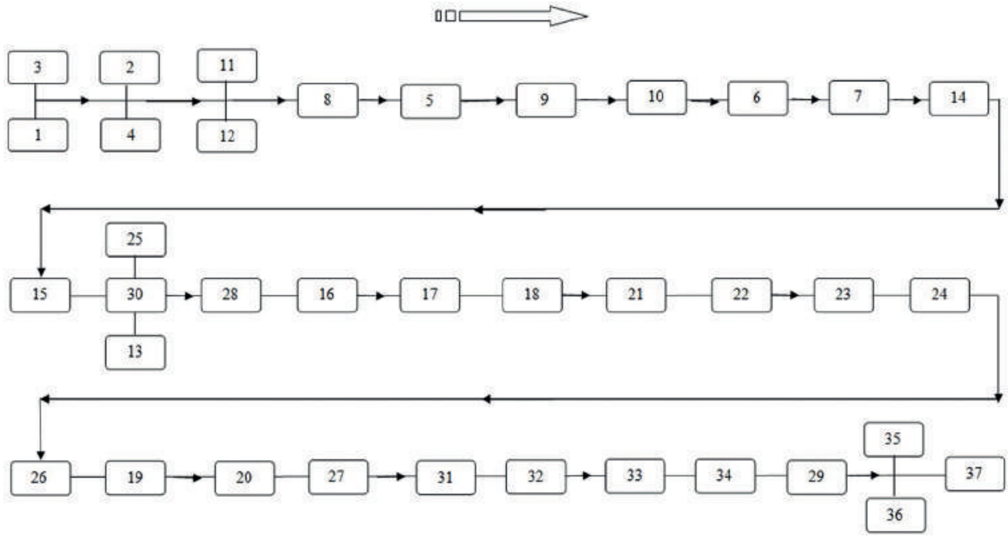

Figure 2. *Current Status of the Cruising Program Flow Diagram (Simulation Model)*

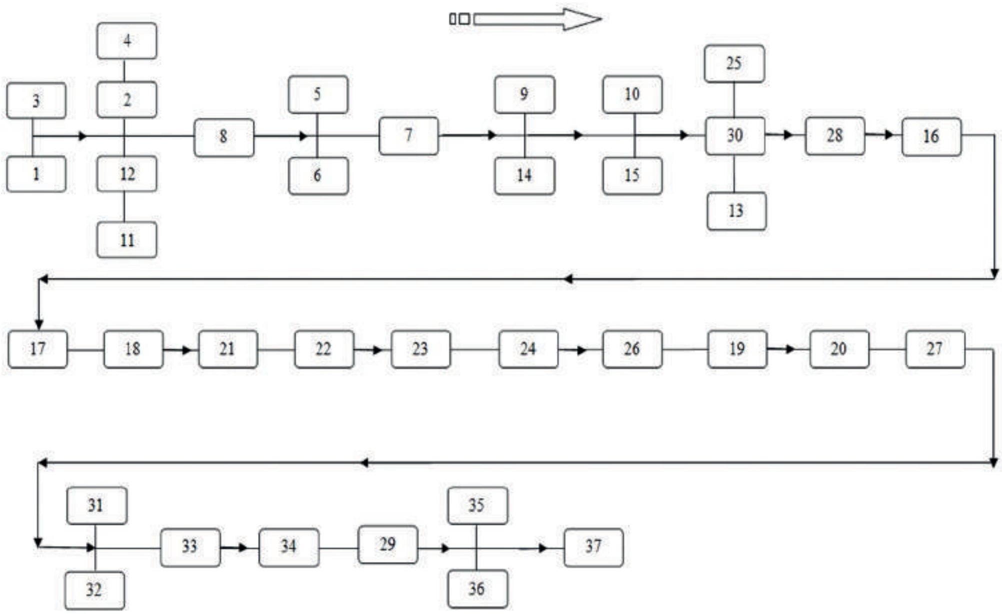

Figure 3. *New Status of the Cruising Program Flow Diagram (Simulation Model)*

3.3. Improvement of the Sea Trial Simulation Model

In order to conduct the cruising program more efficiently, which is composed of 37 items shown in Table 1 , the test flow created to be used in the SIMIO program has been rearranged to provide better results (Figure 3). While preparing this flow diagram, tests that could be done in the same time frame and that will not affect each other were carried out with the help of the experiences gained in the previous sea trial tests. Hence, a certain sequence was followed during the tests, taking factors, such as the position and the speed of the ship, and the difficulty of the test into consideration.

The intended purpose here is to finish the sea trial as soon as possible. Entering the test flow diagram created under these conditions into the SIMIO simulation program, the results were examined, and by comparing the two models, the differences during the sea trial have been observed.

4. Results and Discussions

4.1. Current Status of the Sea Trial Simulation Model

Figure 4 shows a 3D image of the simulation model entered the SIMIO program for the current situation. The tests and controls shown in Table 1 have been entered to the program as activities 1, 2, etc. with the sequence numbers specified in accordance with the current state simulation model (Figure 2).

After creating the cruising program simulation model in the program under normal conditions, the program has been run to find out how long the tests will be completed, and the total cruising duration has been observed as 28,0989 hours (Table 2).

4.2. After the Improvement of the Sea Trial Simulation Model

Following the findings obtained for the current situation, a new simulation model program has been entered into the program by making a series of improvements. Figure 5 shows the 3D model of the simulation model. The tests and controls shown in table 1 have been entered into the program as activities 1, 2, etc. with the sequence numbers specified in accordance with the simulation model after improvements (Figure 3).

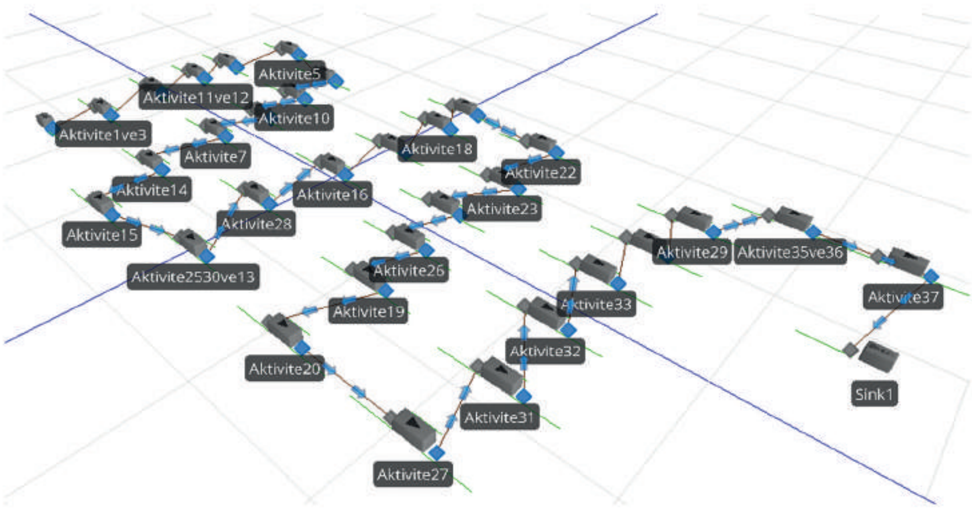

Figure 4. *The Cruising Flow Diagram Provided from the Program*

Table 2. *The Result of Current Status of Simulation Model*

Time In system-Average			
Object Name	**Data Source**	**Category**	**Value**
Ship	[Population]	Flow Time	28,0989
Sink1	[Destroyed Entities]	Flow Time	28,0989
Time In System-Maximum			
Object Name	**Data Source**	**Category**	**Value**
Ship	[Population]	Flow Time	28,0989
Sink1	[Destroyed Entities]	Flow Time	28,0989
Time In System-Minimum			
Object Name	**Data Source**	**Category**	**Value**
Ship	[Population]	Flow Time	28,0989
Sink1	[Destroyed Entities]	Flow Time	28,0989

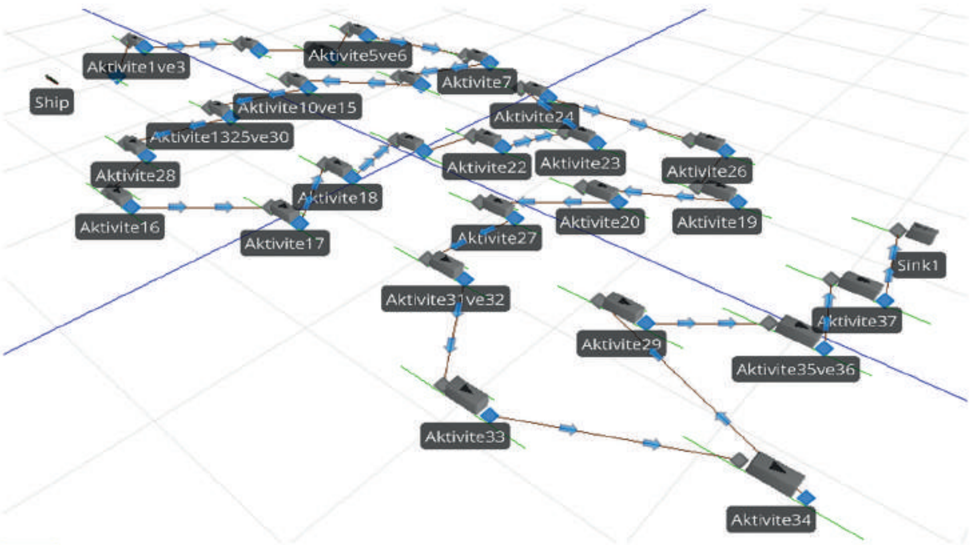

Figure 5. *The Cruising Flow Diagram After the Improvement*

After creating the new model in the program under normal conditions, the program has been run to find out how long the tests will be completed, and the total duration has been recorded as 25,3567 hours shortened by 2,75 hours for the new situation (Table 3). This amount of shortening corresponds to 9,76% of the total cruising time calculated before the improvement.

In the tests carried out on the program, it was accepted that there was no breakdown of the ship during the period from the beginning to the end of the tests and that the weather and sea conditions were suitable for cruising.

***Table 3.** The Result of the New Status of Simulation Model*

Time In system-Average			
Object Name	**Data Source**	**Category**	**Value**
Ship	[Population]	Flow Time	25,3567
Sink1	[Destroyed Entities]	Flow Time	25,3567
Time In System-Maximum			
Object Name	**Data Source**	**Category**	**Value**
Ship	[Population]	Flow Time	25,3567
Sink1	[Destroyed Entities]	Flow Time	25,3567
Time In System-Minimum			
Object Name	**Data Source**	**Category**	**Value**
Ship	[Population]	Flow Time	25,3567
Sink1	[Destroyed Entities]	Flow Time	25,3567

Examples to the differences between the first cruising model and the second cruising model:

- Tests number 5 (boiler controls and alarms) and 6 (bow thruster STBS), which are planned to be carried out sequentially in the first cruising model, were determined as parallel tests in the second model with different personnel in the same time zone.
- Likewise, the tests number 10 (separator test and its alarms) and 15 (anchor windlass PS), which are planned to be carried out sequentially in the first cruising model, have been shown parallel in the second model.
- In addition, the sequence of the tests has been changed in general.

5. Conclusions

In this study, it is emphasized that the sea trial can be completed in a shorter time. For this purpose, the tests to be carried out in the cruise are shown in the form of items with their periods, and the periods of the tests to be entered into the SIMIO program have been determined in accordance with the triangular distribution.

The flow diagram of the test plan formed under normal conditions has been prepared and entered to the program. The program has been run afterwards, and it has been understood that the total time spent on the tests during the sea trial is 28,0989 hours. Then, the new flow diagram created as a consequence of the improvements made on the test plan has been entered to the program again. As a result of this process, it is seen that the total time spent on the tests is 25,3567 hours. As a result, when the flow chart is formed after the improvement is applied, the cruise is completed in less than 2.75 hours. In this case, the total spent time for the cruise tests decreased by a 9,76% ratio compared to the first case. Thus, it can be deduced that the test procedure in the second cruise flow diagram is more useful. What is important here is to ensure that the necessary arrangements in the tests are carried out in parallel (in the same process) with the cruise and that the personnel comply with the work plan. This will shorten the total time spent on tests.

In subsequent studies related to the sea trial, better results can be shown in terms of reducing the total spent time on the tests by designing different scenarios on the cruise flow diagrams formed for the tests. Similar simulation studies can also be conducted on military ships that have more sophisticated sea trial procedures than merchant ships. It is understood that it would be useful to use these and similar simulation programs effectively in the shipbuilding industry to be able to produce high quality ships in a shorter period and to improve the on-time delivery performance of shipyards.

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Measurement and Modelling of Particulate Matter Emissions from Harbor Activities at a Port Area: A Case Study of Trabzon, Turkey

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ABSTRACT

Due to the versatile activities caused by the services provided at the harbor, a large amount of particulate matter is emanated. The health of living things is seriously threatened by the spread of these substances in the air due to the effect of many environmental factors. The size of this threat may reach much higher levels, especially at ports located close to city centers. In this study, at the Trabzon Port area, PM_{10} and PM (deposited dust) measurements from the harbor activities were carried out at 9 different points between February 2019 and April 2019 and the dispersion of these particulate matter into the environment is analyzed utilizing the ISCST3 (Industrial Source Complex - Short Term) model program. It is detected that the highest amount of measured PM_{10} (suspended particulate matter) is at the dock 3 with 1.84 mg/Nm^3 and the highest amount of PM (deposited dust) is in the dock loading area with 203 mg/m^2-day. In the modelling study, it is determined that the particulate matter disperse around an area of 25 km^2 in the south direction of the port, and it is concluded that port air quality management will focus on precautions for docks where intensive loading-unloading activities take place.

Keywords

Harbor Activities, Particulate Matter, Emission Modelling, Air Pollution.

1. Introduction

The globalization of the world economy, the liberalization of trade and the formation of the international transportation market have contributed greatly to the development of logistics and thus ports have become the key point of world trade [1]. In our world, where global trade is rapidly developing and 90% of its trade is carried out via sea transportation, the demand for port services has also increased significantly [2]. It is possible to divide port services into two main groups as rendered services to cargos and ships [3]. Services under the two main groups in question can be stated as unloading, loading, pilotage, towage, storage, temporary storage, sheltering, loading-unloading in container, weighing,

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water-electricity, waste and passenger services [4]. Ports, generally established at close regions of urban areas, have a significant impact on the air pollution of their regions [5]. Particularly, loading, unloading, transport and storage of loads such as cement, coal, minerals, soybean and flour cause significant increases in airborne particulate concentrations [6].

Given the fact that more than 50% of the world's population live in coastal cities [7], emissions from port activities may have a strong impact on the health of coastal communities and the environment [8]. For this reason, in the recent years, many studies have been conducted on the assessment of the impact of port emissions on air quality at a local scale and climate at a regional scale [9][10][11][12][13].

In the case when granule size of the substances (particulates) which is in a solid-state in the atmosphere is less than 300 microns in size, they are called as dust. 50 microns is the limit of vision with the naked eye while the particulates that can reach our lungs are those with a size of 10 microns or less (PM_{10}) [14]. Some studies in the literature [15][16][17] indicate that atmospheric particulate matter (PM) in urban areas is linked to the number of daily mortality and hospitalizations as a result of lung and heart diseases.

In 2000, it was calculated that the human lifespan in Europe has been shortened approximately 8.6 months due to PM exposure. Resulting from this particulate exposure, acute upper respiratory tract infections such as sore throat and coughing could be experienced, furthermore it has been concluded that diseases like bronchitis, chronic obstructive pulmonary disease (COPD) and asthma are closely related to high levels of PM_{10} [18][19].

It has also been reported that the increase in seeking medical advice with cardiovascular system diseases such as vascular occlusion is linked with PM concentration level. Additionally, this exposure to PM is reported as causing cardiac arrhythmia [20].

The results of a cohort study conducted in USA revealed that the 10 $\mu g/m^3$ increase in PM concentration is associated with a rise in mortality rates by 13%. Another cohort study by American Heart Association has also demonstrated that 6% increase in mortality rates depending on 10 $\mu g/m^3$ increase in PM concentration [21].

Many diseases caught in Trabzon are due to particulate matter-based air pollution and some of them even resulted in death. About 200 people died in the province due to diseases caused by air pollution between 2005-2007, while approximately 9000 people received inpatient treatment at hospital [22].

When the pollutant amounts from port activities in European harbors were examined, it has been determined that the amount of particulate matter obtained constitutes 40% of all pollutant amounts [10]. In the literature review conducted in line with this information, many studies have been found on PM_{10} (particulate matter suspended in the air) emissions resulting from port activities [23][24][25][26][27][28][29][30], however, it is observed that there has not been any modelling carried out related to the dispersion of emissions to the environment. In addition, when going through the studies examining the emissions of PM_{10} and PM (deposited dust; including particulates larger than 10 microns) together, although studies have been conducted on PM_{10} and PM (deposited dust) measurements in the facilities such as cement plant [31][32], thermal power plant [33], mines [34]. Additionally, many studies measuring and modelling PM_{10} and PM (deposited dust) emissions together from port activities [35][36] could be found in the literature, however the number of studies which integrate modelling, real-time measurement and dispersion is scarce. Therefore, in this study, PM_{10} and PM (deposited dust) measurements were carried out at Trabzon Port by selecting the city of Trabzon, which is located in the centre rather than having the port area close to the city centre, and its effect on the environment is investigated by modelling study. Thanks to this study, it is tried to be find out which region of the port the emissions from port the emissions originating from port activities were more intense. In addition, thanks to the modelling study, revealing the dispersion and impact areas of these emissions is aimed. It is estimated that the study will be effective both in terms of helping port authorities in determining emission sources and guiding the studies to be carried out at other ports.

2. Methodology

2.1. Measurement Site and Instruments Used

PM_{10} and PM (deposited dust) measurement area is the port of Trabzon (shown in Figure 1), which is the most active harbour of the Eastern Black Sea, (between 40 57' 30" North - 41 06' 36" North latitude and 40 02' 30" East - 39 25' 00" East longitudes) in the north east of Turkey. At the port, three separate daily (24 hours) measurements were made for PM_{10} (suspended particulate matter) and two separate daily measurements were made for PM (deposited dust) for per month. Three different measurements were made for per month at the port at 5 different points for PM_{10} and two separate measurements at 4 different points for PM (deposited dust). The first period measurements took place between February 3rd 2019 – March 4th 2019, and the second period measurements took place between March 4th 2019 – April 4th 2019.

Consisting of 9 docks, the port has an annual capacity of 10 million tons of cargo handling and 2500 ships reception per year. In 2019, a total of 1,869,725 tons of unloading operations were performed and 568,950 tons of cargos were loaded. There are annually 5 million tons of cargo

Figure 1. *Demonstration of the City Where the Port Chosen as the Study Area on the World Map and Satellite View of the Trabzon Port*

storage area and 250 tons of bilge storage area at the indoor and outdoor storage areas within the port. In addition, 24-hour pilotage and towage services are provided at the port, which has 350,000 TEU container handling and 300,000 TEU container storage area annually. Apart from these, there is a passenger terminal in the port where approximately 50,000 passengers enter and exit annually. In addition to these indicated areas, the free zone of Trabzon province is also located within the port boundaries. In this region there are two covered storage space with a capacity of 11,000 m^2 and an open area with a storage capacity of 20,000 m^2.

The names of the codes of all emission sources detected, measured and evaluated in this study as a result of on-site inspections within the port and the parameters measured in these sources are given in Table 1. Moreover, the locations where PM_{10} measurement areas located in the port's general settlement are shown in Figure 2 with satellite photographs, and the locations where the PM (deposited dust) measurement sites were located in the general location of the port are shown in Figure 3 with satellite photographs.

Table 1. *Measured Emission Sources*

Code	Name of Emission Source	Parameters	
		PM_{10}	PM (deposited dust)
1	Stock Area (warehouse area)	x	-
2	Dock 3 (loading-unloading)	x	-
3	Dock 4 (loading-unloading)	x	-
4	Beside Weighbridge	x	-
5	Truck Crossing Road (small port)	x	-
6	Beside Guest Parking Area	-	x
7	Front of Dock 3	-	x
8	Next to Loading Area 4-5	-	x
9	Bilge Area	-	x

Figure 2. *PM_{10} Measuring Points*

Figure 3. *PM (deposited dust) Measuring Points*

Official permissions for performing necessary measurements were granted from port authority prior to the study and the researcher also contacted with port management company and guaranteed their support for the study.

2.1.1. PM_{10} Sampling Method

EPA 40 CFR PART 50, one of the gravimetric measurement methods, is a widely used method for the measurement of particulates called PM_{10}, which exist in outdoor air as suspended in solid state. The sampling process was carried out by determining the most suitable distances for the emission sources specified in Figure 4 (1)-(2)-(3)-(4)-(5).

The PM_{10} absorption nozzle of the Zambelli Iso Plus 6000 dust sampling device was located at a certain height and the device was operated. The air sample taken at constant flow rate at appropriate points around ambient dust sources was passed through the appropriately conditioned filter. It held on to the suspended PM_{10} filter in the environment. After the measurement was concluded, the measurement data was taken from the device and recorded on the measurement form. The filter used in the measurement was carefully removed, placed in a petri dish and brought to the laboratory by labelling. The filters used in the sampling were weighed by waiting 24 hours under weighing room conditions (20 °C ± 1 °C temperature and 50% ± 5% humidity). Dust concentration was calculated as mg/Nm^3 by proportioning weighing results in to the volume of air drawn. PM_{10} measurement results were obtained by performing this process between February and April 2019 3 times for each measurement point and 15 times in total.

Figure 4. *PM_{10} Measuring Points, (1) Stock Area, (2) Dock 3, (3) Dock 4, (4) beside Weighbridge, (5) Truck Crossing Road*

2.1.2. PM (Deposited dust) Sampling Method

TS 2341 standard, which is a gravimetric measurement method, has been taken as basis in collecting PM (deposited dust) samples. This standard comprises methods for the construction, installation and operation of the sediment collection device, which is used to collect and measure deposited dust in the atmosphere, that collapse with their own weight or rain, and so on.

The deposited dust unit used in sampling, which is placed at points in Figure 5 (6)-(7)-(8)-(9), generally consists of: stand, sump case, collecting bottle and connecting pipes. The stand was approximately 1350 mm tall and the protective cage against birds was selected with an aperture size of approximately 0.7 mm. The stand was fixed with a suitable fastener to prevent the collection bottles from falling off the shelves where they were located. The sump case was selected from a suitable plastic material that was resistant to chemicals and not charged with static electricity.

Each sump case was marked with a serial number, with getting a conversion factor (F) for each container, and the calculations were made over this F factor. The conversion factor was calculated from the average effective diameter of the sump case. The average of these 24 measurements was taken at 12 points around the container by measuring the inner and outer diameters. Thus, the D diameter required for the conversion factor was obtained. The dimensions were rounded up to the nearest millimetre and factor (F) was calculated as $1/m^2$ with the following formula. When the weight (milligrams) of the collected sediment was multiplied by this factor, the result was milligrams per square meter (mg/m^2).

$$F = \frac{127{,}3 \times 10^4}{D^2} \quad (1)$$

The measurement period was 2 (two) measurements per month at the points specified in Figure 5 and at specified periods, and a total of 2 (two) months. The average

Figure 5. PM (deposited dust) Measuring Points, (6) beside Guest Parking Area, (7) front of Dock 3, (8) next to Loading Area 4-5, (9) Bilge Area

amount of dust settled in one day was calculated by dividing the monthly values by the number of days.

2.2. Air Quality Modelling

The air quality modelling process is prepared using the ISCST3 (Industrial Source Complex– Short Term) model program approved by the U.S. Environmental Protection Agency. The ISCST3 model is an internationally recognised modelling program used worldwide by many researchers, supervisory and authority bodies to predict pollutant concentrations. Gaussian Distribution [37] forms the basis of the model. With this model, many emission sources can be modelled simultaneously or separately. ISCST3 calculates the distribution of emissions from sources around these group of resources, long-term concentrations at ground level or at desired height, and ground-level precipitation.

In order to use the modelling program, source, emission data and meteorological and topographical data were inputted into the program. The meteorological data were hourly wind blowing directions and frequencies, hourly wind speeds, average hourly temperatures, daily average mixture height and stability class values. The evaluation of stability classes is made according to the stability categories of Pasquill [38]. In addition, in accordance with meteorological data, wind rose was created based on the direction of wind and the number of blows. For topographical data entered in the model, topographic map of the region was used. Cartesian and polar coordinate systems were inputted into the modelling program. The examined region was divided into 500 m. intervals (x-y axes) in the range of 0-2 km and the average concentration values were determined at the designated receiving points. In order to see the effect of the buildings around the port to dispersion, the heights of the buildings around the port as well as topography were also typed into the model.

The concentration areas were calculated for each source and thrown into a common polar and Cartesian coordinate system. Finally, emissions from all sources were collected. The model also could take emissions from volume and surface area into account. As a result of operating the model, monthly and annual average PM concentrations amounts were obtained at the port and the annual distribution of these PM concentrations was determined.

3. Results and Discussion

3.1. Particulate Matter Measurement Results

The first, second and third measurement results obtained from 5 sources, and the mean and limit value of these values are shown in Table 2 for the emission of PM_{10} within two months.

Table 2. *PM_{10} Measurements Results*

Code	Name of the Source	Measurements (mg / Nm³)			Average Value (mg / Nm³)	Limit Value (mg / Nm³)
		1st measurement	2nd measurement	3rd measurement		
1	Stock Area (warehouse area)	1.50	1.36	1.44	1.43	3.0
2	Dock No 3 (loading-unloading)	1.56	1.84	1.70	1.70	3.0
3	Dock No 4 (loading-unloading)	1.84	1.36	1.50	1.57	3.0
4	Beside Weighbridge	1.78	1.48	1.58	1.61	3.0
5	Truck Crossing Road (small port)	0.90	1.08	0.78	0.92	3.0

In the examination, it is detected that the highest value for the first measurement was at dock no. 4 with 1.84 mg/Nm^3. It is seen that the lowest PM_{10} concentration was on the truck crossing road with 0.90 mg/Nm^3. When checking the other two measurement results, it is determined that the lowest values obtained were in the same direction with the first measurements, but the highest values were due to the dock 3. When examining the lengths and depths of docks 3 and 4; it is determined that the dock number 3 was 580 meters long and 10 m deep and the dock no. 4 was 290 m. long and 12 m. deep. Whereas the dock was capable of accepting more ships than the dock 4 at once, the ships with more draft could berth to the dock 4. These two conditions are factors that affect the increase of handling activities and accordingly increase of PM_{10} emissions. As it can be seen from these results while the first measurement was carried out, more ships were loaded and unloaded at dock 4; dock 3, which had the capacity to accept more ships was working more actively during the period of the other two measurements. As a result of the results obtained, we can clearly say that the dock length and dock depth directly affected the PM_{10} concentration formed in the port. When the average values are taken into consideration, it is understood that the length of the dock is more effective than the depth of the dock in terms of the effect on the emission amount.

Considering the wind direction in the port, it is determined that these concentrations did not exceed the Turkish air quality limit value of 3.0 mg/Nm^3 as a result of the measurement values obtained at 5 points 3 meters away from the dust source (PM_{10}) (suspended particulate matter). It is also observed that the European PM_{10} concentration limit value, which was 50 μg / m^3, had not been exceeded. Although the limit values had not been exceeded, if we evaluated the air quality of the region in terms of the location of the port, the fact that a port located in the centre of the city polluted the air that much might cause problems to be concerned with human health.

The mean and limit values are shown in Table 3 with the results of 2 periods of PM (deposited dust) in 4 different points at the port. When the first and second period measurements are examined, it is determined that the amount of deposited dust beside the dock 3 and the loading area 4 – 5 which were the active areas of the port, was much more than the bilge area and the harbour's guest car park which were in the scope of harbour. It is clearly seen that the highest PM (deposited dust) value was in the 8-coded region in the 2nd period measurements with 203 mg/m^2-day and the lowest value was in the 6-coded region with the 80 mg/m^2-day. As it can be clearly understood from these results, although the amount of PM (deposited dust) caused by the port operations had affected the port's impact area, it is determined that the

Table 3. *PM (deposited dust) Measurement Results*

Code	Name of the Source	1st Measurements (mg/m^2-day)	2nd Measurements (mg/m^2-day)	Average Value (mg/m^2-day)	Limit Value (mg/m^2-day)
6	Beside Guest Parking Area	80	82	81	450
7	Front of Dock 3	191	185	188	450
8	Next to Loading Area 4-5	185	203	199	450
9	Bilge Area	86	84	85	450

significant amount of it accumulated in the active areas of the port.

It is determined that the limit value of 450 mg/m^2-day was not exceeded, when the results of the deposited dust measurements carried out in the port are evaluated in accordance with the Turkish Air Pollution Regulation.

Loading, unloading and storing operations that might cause dust emission are carried out at the port. Emission factors are calculated based on the mass flow rate of the measurements made, based on the hourly production amount of 2,248 tons/hour. Emission factors are determined as 0.005 kg/ton for loading and unloading and 2.9 kg dust/ha per day for storage. In accordance with the specified processes, mass flow is found to be 11.24 kg/hour for loading and unloading, and 0.15 kg/hour for 1.3-hectare (ha) storage. The total amount of emissions discharged to the atmosphere from the places other than the chimney is determined as 22.63 kg/hour. This is approximately 23 times over the limit value determined by the Turkish Air Pollution Regulation as 1.0 kg/hour. As a consequence of this result, it is clearly seen that the dust emissions caused by the operation in the ports reached very dangerous levels.

3.2. Air Quality Model Results

As a result of the researches, climate and different factors related to climate and occupy an important portion of the amount of air pollution, along with some other geographical factors such as geographical location and topography. It is possible to sort these climate-related factors affecting air pollution in the form of wind, atmospheric stability and thermal inversions, topography [39]. In this respect, the port region wind rose created by using the data obtained from the meteorology station is shown in Figure 6.

As a result of the model study, when we examine the wind speed and directions that were effective in emission distributions; according to the specified measuring station data; the average wind speed was of 1.8 m/s per year. Wind speeds ranged from 1.5 m/s to 1.9 m/s in different months. The first-degree prevailing wind direction in the region was the south-southwest (SSW) direction with a breeze number of 3477.

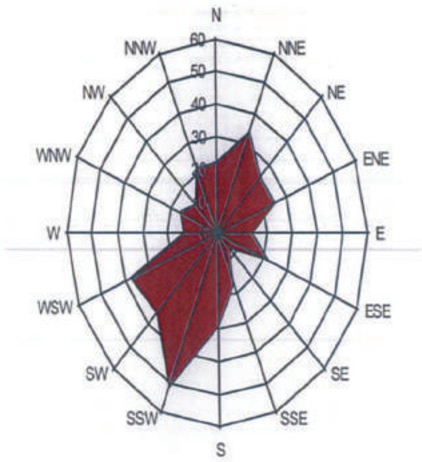

Figure 6. *Trabzon Port Region Wind Rose*

Monthly emission values and the annual average emission value obtained as a result of the air quality modelling study conducted to determine the concentrations of dust emissions emitted from the port around the port are given in Table 4. Higher values were obtained in many points due to the increase in PM_{10} concentrations in the air and dust emissions from the ground, especially in the summer with the decrease of precipitation in the region. However, it is thought that the high values in the winter months such as December and January, which are determined from time to time, might be due to household heating aroused from the sampling point in the settlement area and also due to the increase in the number of ships arriving at the port during these periods.

In addition, when the monthly PM concentrations values obtained as a result of the air quality modelling study given in Table 4 are examined, it is clearly seen that the lowest value is the value in April, which is one of the most precipitation months of the province with 9,2180 mg/m^2-day. As a result of these values, it can be predicted that seasonal changes as well as the number of ships affect the amount of dust emission at the port. Although developed countries have recently noticed the global damages of fossil fuels, the widespread use of these fuels still continues. Coal firing causes the release of dust pollutants such as particulate matter (PM) into the air [40]. In Turkey, which is poor in terms of oil and gas resources, the situation is progressing with the use of low-quality lignite in energy production. China imports the world's largest stone coal, and Turkey is the 7th largest importer. Turkey is the country planning the most lignite and stone coal-fired thermal power plants in the European Region in terms of number and capacity [40]. Therefore, it is understood that the emission value, which had an average annual value of 21,3335 mg/m^2-day, is very close to the values in September, November, December and January, and emissions from household heating in the region had a significant impact on port emission values.

Table 4. *Amounts of PM Deposition Obtained by Air Quality Modelling*

Months	Particulate Matter (mg/m^2-day)
January	22,60
February	17,07
March	18,64
April	9,21
May	13,79
June	15,69
July	17,34
August	28,64
September	22,71
October	24,85
November	21,67
December	25,69
Annual Average	21,33

When the obtained results were compared with the measurement results made in a coal-fired thermal power plant, it was determined that the measurement results obtained at the port were almost half lower than the measurement results at the thermal power plant (the mean PM measurement results between 2013 – 2017

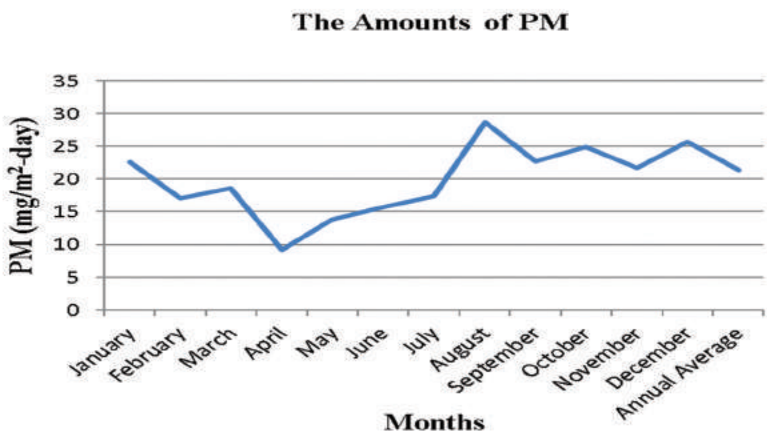

Figure 7. *Monthly and Annual Average Amount of PM Graph*

for 4 points were 69.41; 30.32; 30.97; and 26.44 mg m^2 day respectively [33]).

The distribution graph obtained as a result of the air quality modelling study conducted to determine the distribution of dust concentrations emitted from the port around the port is given in Figure 8. The wind rose prepared for annual blow numbers and directions where the wind came from and the distribution graph prepared for annual average concentrations shows that the model consequences gave results consistent with the wind rose.

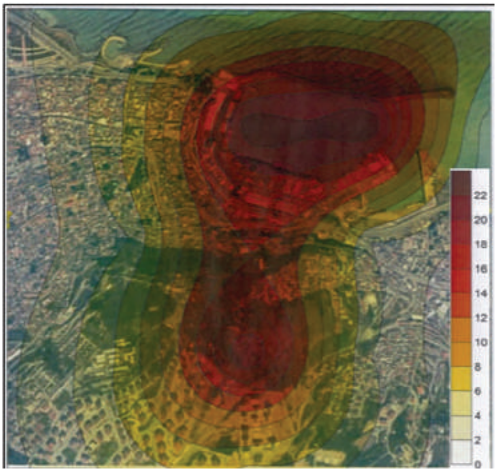

Figure 8. *The Particulate Matter Concentration Map*

In the examination made on the particulate matter concentration map, it is determined that dust emissions affected an area of approximately 25 km^2. As it can be seen in Figure 9, the port subject to the study is one of the rare ports in the centre of the city where it is located and so close to the city centre. The 25 km^2 impact area mentioned above threatens the region where people live intensely and have the highest average population during the day.

There is an international main road with an average of 50 thousand vehicles passing annually, just 100 meters from the south direction of the port area subject to the study. PM_{10}, PM (deposited dust) and VOC (Volatile Organic Compounds) emanating

Figure 9. *The Satellite Image of the Closeness of the Port to the City Centre*

from vehicles are important sources of pollution in the urban air. According to TUIK (Turkish Statistical Institute) 2019 data, the exhaust emissions of vehicles which are in traffic create a significant amount of air pollution in our country where there are approximately 7.5 million vehicles over the age of 16 [41]. According to this information, when we think about how the emissions originating from the traffic are distributed in the same direction by combining with the emissions flowing out from the port, it is clear how much the port area poses a human health risk.

Moreover, when the data obtained from the Trabzon-Meydan (Square) measurement station, which also includes the Port region, it is determined that in 323-day measurements from 2019, PM_{10} values are found to exceed the EU limit value in 94 days [42]. When the values measured in the specified station are analysed, it is determined that approximately 32% of these values are emissions originating from the port. In our world where approximately 7 million deaths are caused by both outdoor and indoor air pollution each year [43], the contribution of ports to this pollution is at a considerable level.

4. Conclusions

As a result of operations such as loading, unloading and storage in Trabzon Port and other port activities that take place outside of these, a significant amount of particulate matter (PM) is emitted to the atmosphere. The loading and unloading activities carried out at the dock had the most profound effect on the PM_{10} values obtained at the port area. In addition, storage and transportation activities in the port caused PM_{10} to occur almost as much as loading and unloading activities. These activities that we mentioned also affected PM (deposited dust) emissions, another type of dust. It is determined that PM (deposited dust), which occurred as a result of the activities taking place at the quay, mostly accumulated in the close regions of the quays. It is seen that this effect reduces by almost 50% in the car park and bilge area, which are the impact area of the port.

With the air quality distribution modelling, which is the result of combining the port region with meteorological and topographic data, it is determined that the data obtained from the sources mentioned in the port is affected by dust emitted into the atmosphere as a result of port activities of a region of 25 km^2 including the port. While approximately 2 km^2 of this area constituted the port area, the remaining part is located in the central region of the city. Dust emissions, which can reach approximately 3 km in the east and west directions, can also reach 5 km in the south direction according to the model results. The region, which is stated as the city centre and a high population zone, is located at a distance of 300 meters in the south direction of the harbour, showing that these emissions are highly threatening the living life. Based on the result that the dispersion distances obtained at the selected port will increase or decrease depending on the change of load amounts and wind speeds at ports in other regions, when choosing a port establishment, we can make an apparent deduction that the distance of the port from the city centre is one of the most important factors to be considered.

As a result of the study, it is made out that the wind is the most influential in the dispersion of the dust, which is caused by port activities. At all ports and especially at ports like Trabzon Port, where loading-unloading, storage and transportation of cargos such as coal, cement and grain are the most frequent by ships, these activities may result in generating high levels of dust. In order to reduce dust emission, measures such as placing wind cutting boards at the port area, covering the materials stored out in the open, keeping the upper layers of the materials humid, ensuring regular watering and cleaning of the port roads are required.

Using cyclone separators in port buildings with coal fired central heating systems or making use of alternative energy sources such as electricity or natural gas for heating would decrease the amount of PM emissions. Achieving thermal insulation is also essential for reducing PM emissions. In this way, fuel consumption could be decreased and less air pollutants would be released into the atmosphere. Along with these, green wave can be applied on the road near the port for a continuous traffic flow in order to reduce these emissions caused by vehicles, which are occurred generally on acceleration and braking.

In line with this study, estimation of future emissions can be carried out by using the number of ships arriving the port and the data from cargo handling with regression analysis method. Accordingly, necessary preventions could be taken for potentially more serious air pollution threats.

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Is Existing Maintenance System Adequate for Sulphur 2020 Amendments?

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ABSTRACT

Sulphur 2020 regulation as a reduction of sulphur emissions has been caused a big challenge via using new fuels in the maritime industry. Consistent changes in the chemical and physical properties of these new fuels make classical maintenance methods as brake down or planned inadequate and endanger operational and navigational safety on ships. Within this framework, ship maintenance systems need to be reevaluated in accordance with the new marine fuels.
In this study, firstly impacts of new marine fuels on ships have been evaluated by means of a literature review. Furthermore, repair and maintenance systems have been presented that are currently used on board ships. Subsequently, advantages of a predictive maintenance system that will reduce risk by constantly monitoring the potential critical characteristics of VLSFO over other maintenance systems have been discussed. Then, assessments of compliance fuel have been done in accordance with fuel properties, problems and corrective actions. Lastly, discussions and suggestions have been provided to the ship owners and technical managements.

Keywords

Sulphur 2020, VLSFO, Predictive Maintenance, Marine Engines.

1. Introduction

Nowadays, ships have faced with new technical problems via using very low sulphur fuel oil as of Sulphur 2020 Regulation which affect many parameters in the maritime industry. There are three major alternative solutions in order to comply with new Sulphur regulation that are firstly using of very low Sulphur fuel oil (VLSFO) or marine diesel oil, secondly exhaust gas cleaning system such as scrubber and thirdly the use of nonpetroleum-based fuels as liquefied natural gas [1]-[3].

SOx emission is not the only component to be controlled on marine diesel engines. Also, a method that reduces SOx emissions should not have an increasing effect on

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other polluting components.

While SOx emissions have been significantly reduced with the scrubber systems as an exhaust gas cleaning system, the additional energy as a fuel consumption for the operation of the system and the neutralization of the acidic washing water in scrubbers will considerably increase the CO_2 emissions [2][4].

In addition, the control of a very complex chemical process complicates the operational process of scrubber. Moreover, using of a separate tank for the storage of sludge generated during the SOx binding of NaOH using in decomposition of SOx and the disposal of the sludge formed at certain intervals causes additional operating costs and increased personnel workloads.

The effects of alternative fuels and exhaust gas cleaning systems which are used to reduce SOx emissions have been compared on the initial investment cost, operating costs, storage requirements and SOx, CO_2 emissions, in Table 1 [2][5][6].

1.1. New Marine Fuels and Impacts on Ships

The approximate number of ships with scrubbers in operation and on order could be determined as 2702 and 2756 by the year of 2020 and 2021, respectively [7]. The rest of ships have been using a low sulphur fuel oil or marine diesel oil with a small modification of engines. As an inside composition of marine fuels, there are kerosene to reduce the viscosity of residues through blending, light and heavy gasoil, diesel, residue fraction with fluid catalytic cracker and visbreaking process. These blends could be produced considering marine fuel standards with maximum density limit that affects ignition quality, maximum silicon and aluminum limits in order to avoid abrasive corrosion inside fuel system; and maximum total sediment limit so as to reduce impurities [2][8].

Hydrotreating, coking and cracking processes remove sulphur in the refinery process [9] which forms inside crude oil from 0.03 to 7.89% [10] by weight. There are negative impacts on producing of large volumes of marine fuel such as unsustainable reliability and lack of experience. For this reason, residues are blended with distillates in refineries so as to obtain low Sulphur fuel oil [2]. This new situation could result with some negative impacts as;

- Negative impacts on combustion chamber of the substances remaining in the fuel as a result of the cracking methods used in obtaining new fuels,
- Negative impact of using wrong cylinder oil with VLFSO on two stroke diesel engine,
- Filtration and separation processes

Table 1. *Comparing of Different Fuels According to Ecologic and Economic Factors [2][5][6]*

	Capital Investments	Operating Costs	Storage	SOx	CO_2
HFO	Low	Low	Unlimited	High	High
HFO/Scrubber	High	Medium	Slightly Limited	Low	High
MGO	Low	Very high	Unlimited	Low	High
Methanol	Very high	High	Limited	Very Low	Very Low
LNG	Very high	Very Low	Limited	Very Low	Low

- Refineries have produced new fuel with different specifications within required Sulphur limits which causes compatibility, stability and waxing problems.

Since there are only chemical tests of new very low Sulphur fuel oil not a tests on marine diesel engines by refineries, the testing and evaluating of the results would be done on existing working ships via try and see method. Unfortunately, this situation strikes the fact that existing ships are used as test tools. Furthermore, the malfunctions and failures that occurred due to very low Sulphur fuel oil could result in detriment of navigational safety and commercial losses.

2. Necessity of New Maintenance System with New VLSFO

Maintenance for the maritime industry includes mandatory requirements that are concern with the maritime regulations. It also has to contribute effective and efficient shipping operations. Furthermore, inspective procedures have been extended due to requirements of classification societies and rule makers [11].

A planned maintenance system which is compulsory application in compliance with International Safety Management (ISM) Code involves schedule tasks. There are also brake down, preventive and predictive maintenance systems which are rarely used on board ships. Conventionally, there are planned and unplanned maintenance systems and also preventive or corrective in compliance with European standard EN 13306: 2017. Furthermore, preventive maintenance can be expressed as time based planned maintenance and conditional maintenance [12][13].

In maritime industry; scheduled replacement, scheduled overhaul, corrective maintenance, continuous on-condition task and scheduled on-condition task are utilized as the maintenance systems [14,15,16]. Essentially, preventive, corrective maintenance and condition based as predictive maintenance approaches have been expressed among the various maintenance systems [14][17][18][19].

Among these, Predictive Maintenance System has become much more important for the maritime industry with the introduction of new VLSFO fuels. The main objective of the predictive maintenance is originated from the current condition of the engines. Moreover, it can be expressed as monitoring of the machinery and abided by its current condition. It also involves sensor selection and betimes or continuous data measurement with different monitoring of performance, lubrication, thermal, acoustic and vibration [20].

From the different viewpoint, predictive maintenance is policy which uses monitoring data of indirect condition so as to estimate forthcoming malfunctions. There are two kind of predictive maintenance model which contains useful life prediction and maintenance optimization. Thus, it can be expressed as statistical, knowledge based and data driven strategies with feature engineering, overfitting, and regularization [21]. As an example of statistical method, speed and fuel consumption data of 14 months were used for the ship performance evaluation [22].

In substance, predictive maintenance have been predicated on early diagnosis of the engine failures which prevents the degradation of engines. In this systems, machineries are fitted with a sensors and data acquisition system which ensure beforetime failure prediction. Therefore, this will result in firstly higher performance of engines, reduction of spare part usage, enhanced profit and decreasing of maintenance costs [23]. Predictive maintenance also provides a decrease in failure risks and costs, enhance performance in despite of higher initial investment costs [24][25][26].

3. Results and Conclusion

3.1. Assessment of the New Compliant Fuels

Using of 0.5% sulphur marine fuels with an increasing number of different fuel blend types have cause problems such as instability incompatibility. Furthermore, fuel lines, filters and tanks have been redesigned in order to decrease the risk of instability and incompatibility [27].

There are some problems about using compliant fuel as low viscosity, compatibility problems, stability and flash point which are about operational and safety subjects [28]. In this respects, Table 2 illustrates the fuel properties, problems and corrective actions of a new compliant fuel.

3.2. Assessment of the Maintenance System with Compliant Fuels

When considered from the new low sulphur fuel's point of view, especially diesel engines have to be constantly observed while working even if specification of the latest receiving fuel is suitable. This is because of compatibility, stability and other negative impacts of low sulphur fuel. Therefore, this will lead to changes in conventional maintenance and monitoring standards on ships.

Traditionally, breakdown maintenance, planned maintenance and preventive maintenance are insufficient as the unexpected impact of using new low sulphur fuel oil. For instance, piston rings, cylinder liner and fuel pumps could be broken after a few hundred hours of operation. Consequently, the planned maintenance systems which are currently used on the ships could be revised by using predictive maintenance in the critical equipment in the ship engine room. Particularly, it could be applied to the fuel systems due to compulsory drydocking processes.

The new type of fuel has not been tested on current marine diesel engines by manufacturers. Hence, its effects are difficult to predict. Furthermore, the corrosive substances inside the fuel were thrown with sulfur. However it sticks directly with the new fuel because of low sulfur and bonding to the metal and becomes corrosive.

In addition to the frequent analysis of fuels and oils for using of newly used low sulphur fuels, scavenge drain oil and flue gas analysis have also become more important. Because, the effect of additives inside the lubricating oils has a different impact on using of new fuels on ships. In other words, the influence on engines of using new fuel should be constantly monitored such as temperatures, pressures, filters and exhaust gas components as required for predictive maintenance.

3.3. Assessment for Ship Owners

- Shipowners as first generation; moved from other industries to maritime industry and became ship owner-operator. When considering of repair and maintenance on marine engines, generally, the first method of brake down maintenance was utilized for maintenance and spare parts. Planned and preventive maintenance are perceived as unnecessary.
- Shipowners as second generation who are the children of the first generation; although reluctant to planned maintenance, international rules and regulations have been obligated to implementation of planned maintenance.
- Third generation shipowners as ship operators; budgets and targets are so crucial however planned maintenance have been implemented in their companies.

In conclusion, shipping companies should have a purchasing department with planning and reporting. Moreover, risks that will occur when planning or making decisions should be well calculated. Risk assessment has been done. Technical managements of shipping companies has operated shipyard processes, orders, spare part management and engineer officers that are working on ships. Therefore, predictive maintenance has become mandatory in accordance with new fuels

Table 2. *Assessment of Fuel Properties, Problems and Corrective Actions in Accordance with Compliance Fuel*

Fuel Properties	Problem	Corrective Actions
High density [29]	Difficult separation due to unusual density of blend fuel.	To operate the separators serially in Purifier + Clarifier mode, respectively.
High ash content [32]	Excessive corrosion in the piston rings and cylinders. Deposit formation in the exhaust valve, piston ring socket and turbine wings.	Operating the separator with high efficiency and putting filter with low pore diameter (<50μm) in the outlet if necessary.
High vanadium [29]	High temperature corrosion and deposit formation	To use the additives which deactivate the vanadium in order to prevent high temperature corrosion.
Sodium (sea water) [32]	Deposit formation in the turbine wings. Excessive sludge accumulation in the exhaust valves. Deposit formation in the injector nozzle and piston rings.	To operate the separator in low flow rate and high efficiency and to decompose maximum water.
High Al+Si [30]	High corrosion in fuel pumps, cylinder jacket and piston rings.	For classical separators, to operate the separators in serial mode with low flow rate.
Fuel incompatibility [31]	Excessive sludge outlet from the separators, increase of the corrosion in the fuel pumps, deposit formation in the injector nozzle, exhaust valve and turbine.	To perform conformity tests for fuels. If it is not possible to perform compatibility test, to transfer the old fuel in the fuel tanks to other fuels before fuel tank.
High CCAI [29]	Knocking problem	To activate the preheater of the main engine before starting of main engine to keep the engine hot.
Low flash point [31]	Safety storage problem because of lower flash points	Limits to 60 °C according to SOLAS, Protecting fuel leakages in fuel lines and ventilation of service and settling tanks spaces.
Stability [29,30]	Exhibits the potential of particle formation, sediment/gumming during using and storage of fuel due to gravitation of asphaltenes resulting in sludge formation	Not mixing of different fuel blends. Sudden temperature increase and decrease should be avoided during change over period.
Clouding /Pouring [31,32]	It is the flow property in low temperature and affects fuel transfer. High cloud point causes plugging of filters.	Fuel should be heated adequately higher than pour point and probable wax formation point. Thus, the temperature of fuel must keep above 10 °C of cloud Point of VLSFO
Lubricating [30]	Excessive wear on fuel pump and injection valves due to lower sulfur content.	Additives can be used. Measures must be taken that the viscosity will not drop below 2 cSt especially in the transition to low viscosity fuels.

of maritime sectors. Knowledge, skills and experience have become even more important and ship technical management should be done in a more professional way with a separate purchasing, maintenance, education and training department.

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