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Editorial

We are pleased to introduce JEMS 8(2) 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
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Quantitative Analysis of Dynamic Risk Factors for Shipping Operations

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ABSTRACT

Risk assessment activities in maritime transportation are mostly done through fixed risk assessment forms. However, during maritime operations, many different dynamic factors such as visibility, the time period during which the operation is carried out, weather, current speed, tidal status, traffic density, etc. can increase these risks. These dynamic risks are not included in the existing risk assessment forms.

In this study, the dynamic factors that increase the risks in ship operations were determined, and to what extent the variables in the operation quantitatively increased various risks was examined through the survey study conducted. Risk coefficients were collected through a survey study, as a data collection tool, conducted on seafarer who participated in ship operations. Consequently, the type of risk assessment to be performed in accordance with the dynamics was evaluated by adding dynamic risks to the possible static risks in cargo operations.

Keywords

Maritime Safety, Ship Operation, Risk, Dynamic Risk Assessment.

1. Introduction

More than 80 percent of the world trade volume is transported by merchant ships. In early 2019, the total world fleet capacity was 1.97 billion DWT, corresponding to a growth of 2.61 percent [1]. Maritime transport is regarded as the most preferred type of transportation in the world because of the fact that it can carry large amounts of cargo at one time, there is no international border-crossing problem, the loss of goods is at a minimal level and it is safer than other types of transportation [2].

Parallel to the technological and social developments, industrialization and population growth, demand for energy, goods, and food are increasing each day. This brings with it an increase in the number of ships, ship sizes, ship speed and therefore an increase in maritime traffic. The risks neglected regarding ships, in which large investments are made to

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have the potential to cause high costs and disasters. Proper assessment of the risks in such systems forms the basis for taking necessary measures effectively [3].

Occupational activities in many industrial fields provide various benefits to human life. However, such activities may contain potential risks during their routine operations. Therefore, some unexpected errors can occur in accordance with relevant operational tasks. Nevertheless, these errors may have crucial importance as they could lead to very costly results such as loss of assets, operational resources or even human life, which can be affected directly or indirectly. The problem, here, is how to establish human control over potentially dangerous technical operations [4]. Similarly, ship operations may contain many risks due to the hazardous working environment and many exhaustive operations.

Many resolutions, codes, and practices have been made and performed by maritime authorities in order to identify and prevent risks in the maritime industry, and risk-reducing or preventive control measures have been proposed. However, it is seen that many conventions, rules, and codes in the maritime industry were made after accidents. Although continuous measures are taken by maritime authorities to reduce risks, accidents continue to occur.

The disaster that took place in the offshore platform of Piper Alpha in the North Sea in 1988 caused 167 crew members to lose their lives. After the accident, which was the worst disaster in an offshore plant in terms of casualties [5], efforts were made by the International Maritime Organization (IMO) to evaluate safety in the maritime industry and the "Formal Safety Assessment" practice was developed, which was in the form of a guide,. The Formal Safety Assessment Guidelines were approved in 2002 for the IMO to use them in the rule-making process [6]. The guidelines were replaced by MSC/Circ.1180-MEPC/Circ.474 and MSC-MEPC.2/Circ.5. and, MSC-MEPC.2/Circ.12/Rev.2 is the currently-used guidelines [7-9]. The FSA is used as a basis by member states or related committees in the decision-making process of the changes to be made on IMO contracts [10]. It aims to make the decisions taken by IMO more effective and to take measures before accidents occur by adopting a proactive approach [11].

Moreover, the assessment of the risks related to ships was made by companies and static risk assessment forms which has been prepared in order to minimize the effects of these risks. Other than the identified risks, the maritime industry is also under the influence of many dynamic risks such as meteorological events [12], environmental status [13], ship structure [14] and ship stability [15] and the type of operation [16]. When these risks are not taken into account, serious losses are predicted to occur. However, during maritime operations many different dynamic factors such as visibility status, the time period during which the operation is carried out, weather status, current speed, tidal status, traffic density, etc. can increase these risks. These dynamic risks are not included in the existing risk assessment forms. Therefore, the necessity to evaluate under which conditions the dynamic risks changed numerically has emerged. It is important for the safety of the operation to be carried out to update the existing data when new data on both static risks and dynamic risks are available.

Within this context, the paper is organized as follows. The literature review on dynamic risk assessment is presented in Chapter 2. The proposed model is explained and the data obtained are presented in Chapter 3. The experimental study involving the sensitivity analysis to evaluate the survey study and confirm the results is described in Chapter 4. As a case study; the additional risks brought by the dynamic risks affecting cargo operation are examined in Chapter 5. In the last chapter, the results are discussed and recommendations are offered for future research.

2. Literature Review

According to IMO, the only way to take action before a disaster occurs is to use the process known as the Formal Safety Assessment (FSA). IMO defines FSA as a combination of the occurrence probability of danger and the severity of the result [17]. FSA is a risk-based assessment method. It is important to know how to control the system functions and to establish how to develop corrective actions in order to prevent operational-level risks in the system functions so that operations can be carried out in a safe working environment [18].

Because maritime accidents occur due to continuous and variable parameters, risk factors can trigger different incidents and cause different dangers [19]. Risk assessment, in this regard, plays an important role in preventing accidents. Risk assessment is a procedure called regulatory impact diagrams. A regulatory impact diagram may represent "reducing and corrective control measures" such as "probability" and "severity" of an accident, evacuation of people from an affected ship, control and cleaning of the pollution, etc [20]. The outputs obtained from the risk assessment form the basis for the operations carried out on board.

The addition of significant uncertainties and variable factors to the static risks of maritime operations creates a complex and dynamic working environment. Although conventional risk assessment methods play an important role in identifying major risks and ensuring safety, they have a static structure [21]. In an ever-growing environment, risk assessment methodologies and practices have made progress towards a dynamic direction in order to address risk-related issues, support operations and overcome the limitations of conventional techniques. This allows for continuous integration with more accurate data and an optimum risk picture [22]. Dynamic risk assessment (DRA) aims to pay attention to new risk concepts and early warnings and to systematically update related risks and to provide more flexibility [3]. In this way, it informs decision-makers more efficiently for taking early actions [23]. Dynamic risk assessment forms the basis of next-generation risk assessment and risk management approaches [24]. The implementation of procedures and the selection of equipment in cases where dynamic risks emerge will form the basis for determining the techniques to be used for managing the process.

In recent years, many DRA studies, especially on offshore systems have been carried out in the maritime industry. For instance; Ren et al. evaluated the real-time collision risk of ships using the SAMSON risk model and fuzzy logic method [25]. Similarly, Yeo et al., using the dynamic risk assessment methodology based on Bayes Networks, investigated the reasons for the situations that caused collisions, leaks and landing accidents in the unloading operations of LNG carriers in a terminal [26]. Zhang et al, who transformed the Bow-Tie model into Dynamic Bayes Networks, examined the MPD (managed pressured drilling) operations in the offshore oil and gas fields [27].

In another study conducted by Pak et al; the risk factors affecting safety in ports such as weather status, features of channels and types of ships, etc. were evaluated in terms of Korea [28]. Bi et al., who used the MLD (Mater Logic Diagram) dynamic risk assessment model, investigated potential loss due to oil spill and the problems such as environmental damage, loss of goods, health impact and social impact, arising after it [29]. Eide et al. estimated the environmental risk of drift grounding accidents for oil tankers using the dynamic risk approach with real-time and projected risk modeling and investigated the probability of grounding and the impact of oil spillage on the coastline [30]. They aimed to provide a dynamic risk-based positioning of tugboats, using real-time and projected risk models to accommodate the drifting ship with effective support. Dai et al. developed a dynamic risk pre-assessment system model in order to provide early risk warning for traffic safety in marine spaces with limited visibility using the fuzzy system method [31]. Rokseth et al. focused on Dynamic Positioning (DP) systems, where automated control made risk assessment difficult [32]. It is shown that the risk depends on parameters such as time-dependent variables and status variables, failures and event timing. Basic requirements are proposed for operational online risk assessment frameworks. Balmat et al. asserted that a ship's individual risk index can be used in real-time to detect a risky ship [33]. They obtained the fuzzy risk factor from the ship's static risk factor and dynamic risk factor by performing the Maritime Risk Assessment (MARISA) with a fuzzy logic approach. Yan et al. investigated the dynamic obstruction risks of the Yangtze River, in which inland waterway transport is carried out, through the CBR and F-TOPSIS hybrid study [34]. CBR (cost-benefit ratio) was applied to select the most cost-effective one in a dynamic risk environment; and the F-TOPSIS method to assess the dynamic risks of inland waterway obstructions.

3. Methodology

The risks, probability, and effect categories of relevant operations are determined and rated with the risk matrix that is created as a result of the risk assessment [35]. The risks are expressed in numerical values in order to be prioritized. The risk-reducing activities or control measures are determined according to the definitions that correspond to the numbers in the matrix.

A Questionnaire was created to determine the dynamic risks that were identified in the present study. The expressions in the measurement tools were based on a 5-Point Likert Scale (1= Very Low Risk, 2= Low Risk, 3= Moderate Risk, 4= High Risk, 5= Very High Risk). The Statistical Package Program for Social Sciences (SPSS) 26.0 was used for the statistical analysis of the data.

3.1. Determining The Dynamic Risk Factors

Hazard Identification (HAZID) is an analytical technique [36] used to identify the dangers that would lead to a dangerous event if adequate precautions are not taken, and constitutes the first step of any risk evaluation [37]. Different methods are used for HAZID. In the present study, the Brainstorming Method (BS) was used. The Brainstorming Method was first used by a publicist named Osborn in 1957 [38]. Brainstorming, which is used as a tool for enhancing creativity in corporate settings, was also used in the following years in different areas because of its ability to obtain a large number of ideas [39].

The human element also plays an important role in the areas where there is operational activity on ships. A mechanical failure that creates an insecure condition that can cause a human error or an accident can be defined as a triggering event [40]. In the literature; within the scope of risk assessment, many studies focusing on human element issues and using methodological approaches have been conducted. One of these studies, Arslan et al., examined the relationship between the factors affecting the fatigue level of navigational officers and marine accidents, using the SWOT analysis method [40].

Yıldırım et al., used the Analytic Hierarchy Process (AHP) method to identify human errors that caused landing accidents on container ships [41]. Similarly, Arslan et al., analyzed the accidents that occurred during loading and unloading operations at tanker terminals with the Fault Tree Analysis (FTA) method in terms of the human element and tested the results with Monte Carlo Simulation [42]. In addition, Kandemir et al., examined the role of human error during the revision of heavy fuel oil (HFO) purifier with the Shipboard Operation Human Reliability Analysis (SOHRA) approach [43]. Demirel examined the probability of human error in possible faults in gas turbine systems with the Cognitive Reliability Error Analysis Model (CREAM) method [44]. In this study, the human element is not included in the research.

The risk factors were determined for each group of operations with a detailed literature review and by receiving the opinions of experts in the field through BS. The risk factors may vary according to operation groups. The risk factor that did not affect or that was not suitable for the ship operation was not considered for that group of operations. As a result of HAZID, 10 hazards were examined for quantitative risk assessment in terms of the Risk Index. The identified risk factors are shown in Figure 1.

The risk factors were classified as part of the visibility, weather status, time frame of the operation, the speed of the currents, tidal status, traffic density, location of the ship, and the area where the navigating was carried out (Figure 2). The size and type of the ship were classified as non-environmental factors. Visibility was classified as Visibility 1 (Thick Fog), Visibility 2 (Fog), Visibility 3 (Moderate Fog), Visibility 4 (Thin fog/Mist), Visibility 5 (Poor Visibility), and Visibility 6 (Good Visibility). The wind speed, wind direction, and sea status were classified under the weather group, which was the title of a single factor. 1-3 Beaufort, 4-6 Beaufort, 7-10 Beaufort and 11+ Beaufort sub-items were given for the evaluation of the weather status. The time period during which the operation was carried out was classified as day and night. The location of ship is classified as being moored at berth/terminal/port, at anchor, coastal/restricted waters, offshore, near coastal waters/gulf, open seas, narrow canals, straits, and in traffic separation zones. The tidal status was

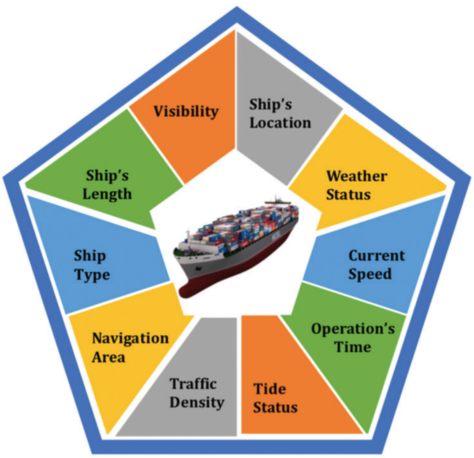

Figure 1: *Structure for Dynamic Risk Factors*

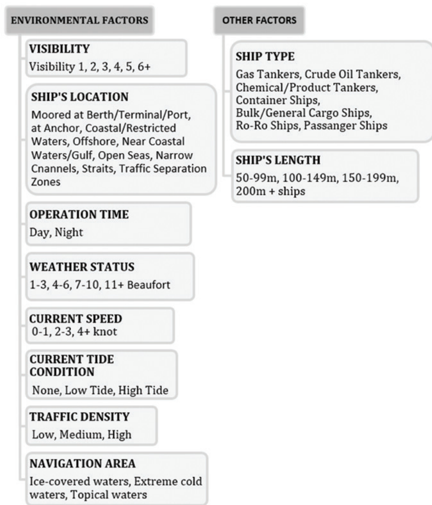

Figure 2: *Dynamic Risk Factor' Classification*

evaluated for high and low tides. The speed of the current was classified according to its being 0-1, 2-3, 4+ knots. The traffic density is classified as low, medium and high traffic. The navigating area was classified as icy waters, cold waters, and tropical waters. The length of ship was classified as 50-99m, 100-149m, 150-199m, 200m and above. The ship type was classified as gas tanker, crude oil tanker, container ships, chemical/product tanker, bulk/general cargo ships, ro-ro ships, and passenger ships.

3.2. Data collection

In this study, a questionnaire was designed and used as the data collection tool for the Turkish seafarers who participated in ship operations. The questionnaire consisted of 88 questions. The questions were intended to determine the factors that affected ship operations according to changing conditions. At first, responses from participants have been gathered to learn about their gender, proficiency and sea experience. In addition, the participants were asked to make evaluations about visibility, location of the ship, time of the operation, the weather, current speed, tidal status, traffic density of the port, ship size, and ship type for 11 different operations groups.

The questionnaire was conducted electronically and with Face-to-Face Interview Method between December 2019 and January 2020. The questionnaires returned from 56 seafarers who were actively working and who had experience for each operation.

The fact that the study was conducted only by the seafarers who had experience on all the operations on board, and that the data were limited to this sampling constitute the limitations of the present study.

3.3. Dynamic risk assessment

80 frequent operations that are carried out on board were classified into 11 basic operation groups with the help of the experts. These basic operation groups are cargo operations, mooring/unmooring/rope/anchoring operations, general maintenance/repair operations, fuel change operations, ballasting/ de-ballasting/ballast exchange operations, operations which are carried out during navigation, operations which are carried out on the deck, emergency operations, equipment failure operations, main and auxiliary machine operations, and other operations.

The study consist of three stages (Figure 3). The questionnaire was designed and the data obtained were analyzed with the SPSS Program.

The Cronbach's Alpha coefficient is based on the number of questions on a scale and on the mean correlation among these reflecting the degree to which these questions measure a common point [45]. This coefficient varies between 0 and 1 and can be used to define the reliability of an analysis. Nunally (1978) reported that the value of 0,7 was an acceptable reliability coefficient [46]. The Cronbach's Alpha Internal Consistency Coefficient that was calculated on the questionnaire data was found to be 0,98 (Table 1). In this respect, the reliability rate of the survey was 98%. The Cronbach's Alpha value and the reliability of the survey being above 0,7 shows that it is within reliable values.

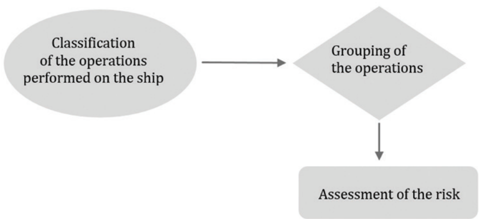

Figure 3: *Stages of the Study*

Table 1: *Reliability Statistics*

Cronbach's Alpha	N of Items
0,986	371

A total of 89,3% of the seafarer who participated in the questionnaire were male (50), and 10,7% were female (7). When the proficiency status of the participants was evaluated, it was determined that 43,64% (25) were Oceangoing Master, 23,64% (13) Oceangoing Chief Officer, 16,36% (9) were Oceangoing Watchkeeping Officer, 3,64% (2) were Oceangoing Chief Engineer, 5,45% (3) Oceangoing Second Engineer, 5,45% (3) Oceangoing Engineer Officer, 1,82% (1) was Captain. In terms of professional experience, it was determined that 20% (11) had 17+ years' experience, 16,7% (9) had 12-16 years' experience, 27,3% (15) had 8-11 years' experience, 20% (11) had 4-7 years' experience, 16,6% (9) had 3 years and less experience. The mean marine experience of the seafarer who participated in the questionnaire was 10,3 years.

4. Finding and Discussion

In the present study, the risk coefficients of the risk factors for ship operations were determined. The priority or ranking of the measures that will be considered to decrease or completely eliminate these risks will be determined with the risk coefficients. The control measures will be determined to control and completely eliminate the effects of these risks with a proactive approach and to control the possible risks that affect the safety of the ship during the operation.

The basic purpose of the present study was to create Dynamic Risk Check Lists considering the probability of dynamic risks of the abovementioned operations becoming a problem and to reduce the effects by determining the risks before they pose hazards.

The risk values of the visibility on ship operations are given in Table 2. It is seen in the table that when visibility drops below 3 in cargo operations, the risk increases rapidly. When visibility drops, the risks that will be posed by loading and emptying equipment on ships may not be predicted. The staff on the deck may not notice the dangers around, and depending on this, negative outcomes may increase rapidly. For this reason, in case of a significant decrease in visibility, the operation must be stopped or reduced to a safe speed. The staff must be informed about possible risks, and the number of the personnel on the deck must be increased. Pak et al. [28] stated that captains were more affected by weather and sea conditions among all port safety factors and that fog was the most important factor affecting air/sea conditions.

The risk values about the weather status on ship operations are given in Table 3. In this respect, when the ship is at the port, it is seen that if the wind force is 1-3 Beaufort, there is low risk; if the wind force is 4-6 Beaufort, there is moderate risk; and when the wind force rises above 6 Beaufort, there is a very strong risk. Loading and discharging operations must be carried out when the wind force is below 5 Beaufort. Operations must be carried out with maximum care in wind force above Beaufort 6. It was evaluated that the risks will increase above 6 Beaufort. It is important to take additional measures to reduce the risks, like increasing the number of staff on the deck, increasing the number of ropes, continuous watch, and informing the crew members on board. Severe weather and sea status play important causal roles in ship accidents. Zhang et al. [47] stated that

Table 2: *Mean of Visibility Status Risk Factor*

Ship Operations	Visibility 1	Visibility 2	Visibility 3	Visibility 4	Visibility 5	Visibility 6
Cargo Operations	4,17	3,61	2,68	2,08	2,36	1,56

Table 3. *Mean of Weather Status Risk Factor*

Ship Operations	1-3 Beaufort	4-6 Beaufort	7-9 Beaufort	11+ Beaufort
Cargo Operations	1,96	3,1	4,26	4,84

when the weather and sea status, which pose a relatively low potential hazard, meet certain conditions, the associated sea conditions may cause a risk for operational activities.

The risk values at the time of the operation are given in Table 4. It is seen in the table that cargo operations are riskier at night. In case of the operations are carried out at nights, further lighting of the deck and informing the crew members about possible risks are important.

Table 4: *Mean of Operation's Time Risk Factor*

Ship Operations	Day	Night
Cargo Operations	2,45	3,64

The risk values of the speed of the currents and the tidal status on ship operations are given in Table 5 and Table 6, respectively. It was evaluated that the risks would increase if the values of the current speed exceed 1 knot in the port. In this case, the numbers, conditions, types and correct positioning of the ropes have become more important. In case of tidal currents, the tensions on the ropes will vary because of the tidal currents and the change in the tidal height. Fast changing of tidal height poses another risk for cargo operations. Tidal status can restrict loading operations. Tanker ships must also care about cargo hoses and arms during operations. The crew members must be informed about the speed of the currents, their directions, low and high tide times. The ropes must be adjusted considering high and low water.

Table 5: *Mean of Current Speed Risk Factor*

Ship Operations	None	0-1 knot	2-4 knot	4+ knot
Cargo Operations	1,5	1,92	2,8	3,96

Table 6: *Mean of Tidal Status Risk Factor*

Ship Operations	None	Low Tide	High Tide
Cargo Operations	1,52	3,29	3,33

The operational risk values for ship types are given in Table 7. It was evaluated that the risks in tanker ships were riskier than in other types of ships. It was also evaluated that, among other tanker types, cargo operations in gas tankers and chemical substance tankers were riskier. Pak et al. [28] stated that the most risky ship type is the second most important ship type of tanker ro-ro ships, in terms of port security.

This paper mainly focuses dynamic risk during cargo operations. When the recent part of the study considered the main dynamic risk are summarized below. The significant increases of dynamic risks are in condition of when the visibility is reduced from 4 to 3; the wind force increased up

Table 7. *Mean of Ship Type Risk Factor*

Ship Operations	Gas Tanker	Crude Oil Tanker	Chemical/ Product Tanker	Container Ship	Bulk/ General Cargo Ship	Ro-Ro Ship
Cargo Operations	4,59	3,98	4,21	2,71	2,47	2,47

to 4-6 Beafourt scale; when the ship is in narrow channels or straits; at nights; when the current speed or tide current speed is more than 1 knots; in heavy traffic; in ice-covered waters; when the ship type is gas tankers and chemical tankers and ships length is 200m and above.

5. Conclusion

In this study, the purpose was to measure the dynamic risk factors in ship operations. For this purpose, the examination of the dynamic risk values for ship operations was carried out with the viewpoint of seafarers. The variable risks in ship operations were determined, and it was evaluated which variables create additional risks to the ship operating in a port. Control measures should be taken, especially when the dynamic risks are in the condition when the visibility is reduced from 4 to 3; the wind force increased up to 4-6 Beafourt scale; at night; when the current speed or tide current speed is more than 1 knots; when the ship type is gas tankers and chemical tankers in cargo operations increase significantly. Control measures and personnel must be informed to carry out the operations more safely.

As a result of the evaluations, it was determined that the increase in the weather status, decreased visibility, the time of operations, and currents or tidal currents cause significant changes on the operations. Ensuring the necessary risk evaluation is made by considering these changes and taking precautions with a dynamic system in which the dynamic risks are included instead of standard risk evaluation forms will improve the safety of operations.

Considering the findings of this study, in further studies, risk factors other than cargo operations can be evaluated in details, and a decision support system can be developed; a system can be developed which will create dynamic risk assessment forms that will consider dynamic conditions.

6. Acknowledgments

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Prediction of Ship Main Engine Failures by Artificial Neural Networks

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ABSTRACT

Maintenance practices are considered as the means of providing safety and security to environment and quality service, and despite increasing the costs for companies with certain increments, they contribute to their reputation and reliability. Maintenance planning of ships consists of setting priorities and planning the efficient use of the sources. One of the main objectives of this study is to bring up more profits from commercial activities by optimizing the availability of vessels. Operational capacity is ensured by adopting a systematic and proper maintenance policy that increases effectiveness and efficiency by reducing downtime. To reach at such a target, recent failure data is analyzed and through this analysis certain procedures are developed for spare parts availability and these procedures are utilized in maintenance applications.
This study aims to provide an additional feature for predictive maintenance software for the analysis of the upcoming conditions of the main engine systems. In this study, the history of failure in the critical nine main engine related subsystems have been analyzed by artificial neural network method, which is consistent with condition-based maintenance applications and subsequently helps to bring out the potential breakdowns in the recorded history of failure.

Keywords

Neural Networks, Planned maintenance, Ship engine failures.

1. Introduction

The main purpose of shipping companies in the maritime sector is to ensure that the effects on people, goods and the environment are at minimum level during the operation of the ships. To achieve this goal, IMO (International Maritime Organization) regulates the rules that can be globally accepted and applied. One of these is the ISM (International Safety Management) Code requires the administration board of shipping companies to ensure that ship operations are safe and secure, that all identified risks are assessed and that

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appropriate safety precautions are taken, land and ship personnel are prepared for safety and environmental emergency and safety management skills are constantly improved [1].

In order to fulfill the requirements of the ISM Code applied to the ships, a Safety Management System (SMS) should be established and the authorities and responsibilities should be determined for the system to work. When the system is put into use, reports should be kept as a result of periodic inspections and should be carried out under the ISM Code regulations to remove any non-conformities that may adversely affect the operation of the system. These non-conformities may be related to administrative or technical matters concerning ship activities. Maintenance of the machinery systems can be done by the personnel working on board, the shipyard or the maintenance team provided from the outsourced services [2]. Machinery maintenance tasks are organized as a result of recommendations of manufacturers, international conventions or experiences gained by companies. The fact that maintenance is applied to ship machinery and equipment periodically, does not mean that there will not be any breakdown between the two-neighbor maintenance. Such points as the quality of the used spare parts, human sourced neglect, oil/fuel quality, weather conditions, route of the vessel, the experience of the previous maintenance personnel may cause any breakdown [3]. In Section 10 of the ISM Code, whilst shipping companies are held responsible for maintenance, how to do so is not limited to certain rules. On the contrary, it is imperative to adopt maintenance policies aimed at minimizing the damage to ships, seafarers, property and the environment.

Conventional fault prediction tools can be seen as a simple diagnostic method to identify the components or the whole system. This traditional technique, however, becomes inadequate when the components get complicated or when the system enlarges excessively, as it can clearly be seen with electric ships. For these complex systems, software tools may offer a solution [4]. For instance, from the manufacturing to the transportation sector, the companies that continue their maintenance and repair operations in an active-reactive manner have changed to complex activities in this regard [5]. Real-time data collection, classification, mapping and recording processes can be fully automated with modern computer technologies at low cost [6].

Considering these described aspects, this study primarily involves the definition of the equipment which will fail because of the unidentified reasons between the two-consecutive maintenance. This prediction would be advantageous in optimizing not only the planning of maintenance applications but also the upcoming navigations. In the remainder of the study, the history of maintenance systems and maintenance strategies will be discussed to find out the tendency, which will help to grasp the gap in the literature. Then the methodology and the history of the failure data regarding the case study will be introduced. Finally, the results will be discussed.

2. Background of Maintenance Systems

All corrective and preventive activities carried out in the name of thorough operation of machinery and equipment are the requirements of production and service facilities, which is called maintenance. The function of maintenance is to restore the machine to its former efficiency due over time, to extend its useful lifetime, or to achieve the expected performance from a totally inoperable state [7], [8]. From a general point of view, the goals of maintenance are high availability, achieving the required quality level, applying safety precautions, realizing the production targets, optimizing energy and raw material usage [9], [10]. Figure 1 summarizes the factors that affect maintenance objectives and why maintenance is needed.

Changes in the maintenance techniques are seen in parallel with the growth in the number of the physical entities and the increasing complexity of them. To be able to distinguish between these changes in maintenance activities, the following points should be taken into account [12]:

- The overall expectations from maintenance,
- Comments on repair and maintenance of the equipment, and,
- Overviewing the changes in the applied maintenance techniques.

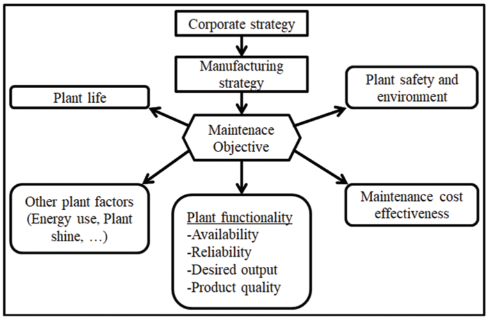

Figure 1: *Maintenance Objective [11]*

Table 1 shows the changes in the expectations, while Table 2 includes the evolution of the methods used to meet these expectations. The first generation covers the time until the Second World War. Following the widespread use of machines throughout the Second World War, expectations paved the way for the second generation. As of the mid-1970's, the acceleration of industrialization has led to the existence of the third generation [12].

Maintenance management consists of processes that include Planning and Implementation sections. In the planning section the correct definition of the strategy requires consideration of working plan and maintenance goals. The success of the maintenance depends on the program, control and inspection processes in the planning session. In the implementation section, it is aimed to achieve more efficient and more economical results than planned tasks [13]. Using a maintenance system with poor maintenance planning or disruptions because maintenance

Table 1: *Changes in the Maintenance Expectations [12]*

First generation	Second generation	Third generation
• Repair when corrupted	• High plant life • Longer equipment life • Lower cost	• High plant life and reliability • Higher safety • Better quality product • No damage to the environment • Longer equipment life • More effectiveness in costs

Table 2: *Changes in the Maintenance Techniques [12]*

First generation	Second generation	Third generation
• Repair when corrupted	• Planned maintenance • Maintenance planning and control systems • Large, slow computers	• Condition monitoring • Reliability and maintenance oriented design • Risk analysis • Small, fast computers • Failure modes and effects analysis • Expert systems • Multiple skills and team work

and repair are critical to the ship; have effects on safety, security, efficiency and environmental considerations. Planning maintenance on ships requires a great effort about complicating time and personnel confinement, safety and security factors, international maritime rules and regulations, environmental risks, emergencies and disasters. Due to the complexity of ship systems, a comprehensive and planned system is needed. For this reason, it is of utmost importance to select the most appropriate maintenance system, implement the most effective strategy, and ensure reliable and efficient ship operations [14]. When establishing a safe working environment, it should be ensured that, in addition to risk assessment, maintenance of machinery and equipment should not lead to any dangerous situation [15]. The fact that ships are used in maritime transport is an important part of the supply chain cannot be denied. Due to the failure of any ship in the transportation system, expenditures will increase on both defective and rest side. The availability of ships depends on how the preventive maintenance system is effective [16].

In the maritime industry, maintenance activities are divided into such three categories, as corrective, preventive and predictive maintenance. The operating costs have been high on the vessels with insufficient maintenance activities; the availability of ship has decreased; and the inspections have increased. As a result of this, the staff on ships have suffered heavy working conditions [17]. Technical status of electrical and mechanical equipment on ships are measured as per such values as power, performance, malfunction and degradation. Due to the variety of the equipment, the relationship between the main structure and the components has had a complex structure. Technical difficulties arise with the addition of technology to the existing structure. The use of scientific information and comprehensive analysis methods seem to be appropriate for this situation [18]. When the ship machinery systems are examined, as a result of regular checks and inspections, it is observed that the condition-based maintenance has become increasingly widespread. The most considerable matters related to the protection of machinery and auxiliary systems are; petroleum (additives), refrigerants, gases, electrical/electronic equipment, gaskets and insulation materials. Improvements in maintenance procedures should be primarily motivated by cost efficiency, increased operational reliability and safety aspects, but should also contribute positively to the environment [19]. The planned maintenance system to be composed covers all belongings of the vessels and keeps a record of their documentation. Records must be on [20]:

- Maintenance log for equipment,
- The time interval for planned maintenance,
- Guiding instructions for staff who works on maintenance,
- The main sources of maintenance.

With the support of current technological infrastructure, different techniques are used to measure and monitor the condition of ship machinery systems. In order to ensure the sustainability of these systems, it is tried to organize an optimum maintenance strategy by examining the instantaneous indicator values and failure records. On this context, Isa et al. [21] (2013), tried to predict the wear conditions of the ship machinery systems by taking samples from the oil circulating in the main engine, generator and gearboxes. It was determined whether these components need maintenance with the analysis of such physical aspects as flash point, viscosity measurement, ferrography analysis and energy dispersive Xray analysis (EDX).

Machinery Risk Analysis (MRA) method

was developed by Dikis et al. [22] (2015) with a methodology involves the generation of a Markov Chain model integrated with the advantages of Bayesian Belief Networks (BBNs). The raw sensor data was firstly classified according to the subsystems and components determined by the experts. In the second stage, the risk and reliability analysis were applied with the probabilistic and mathematical modelling by BBN. The final stage has the decision-making process which involves short and long term predictions and decision features. Finally, the filtered/processed data was transformed into component reliability inputs such as failure rates, Mean Time Between Failures (MTBF) and probability of failure. In this way, failure occurrence, probable time of failure and components, subsystems and systems to be affected are predicted.

Gkerekos et al. [23] (2016), tried to develop a sustainable and profitable maintenance strategy using the ship machinery vibration data. The vibration values produced in the case of a healthy and faulty operation were classified and it was decided what condition the newly acquired data belonged to. In this way, flexible maintenance application is provided by early detection and elimination of emerging machinery failures.

Emovon et al. [24] (2018), wanted to achieve optimum ship main engine system reliability and safety by a sound maintenance management system. To achieve this, risk assessment, maintenance interval determination and maintenance strategy optimization of the system were evaluated by a multi-criteria decision making (MCDM) method.

Lazakis et al. [25] (2018), aimed to provide a systematic approach to identify critical ship machinery systems/components and analyzed their physical parameters though the combination of Fault Tree Analysis (FTA) and Failure Mode and Effects Analysis (FMEA). A dynamic time series was used as input in the artificial neural network to predict future values of physical parameters related to critical ship main engine systems/components. The predicted upcoming exhaust gas temperatures of the main engine cylinders were used for validation of actual observations on board the ship.

Maritime companies benefit from Computerized Maintenance Management Systems (CMMS) which can be embedded in any software or compiled as a standalone version. These systems have the functions of increasing productivity, reducing costs and ensuring that assets are effectively used in manufacturing or service processes. There are countless software companies operating in the field of CMMS due to the diversity of anticipations in the working areas of industrial companies [26]. The main functions of CMMS are expressed as [27]:

- Easy job order management,
- Planning,
- Scheduling,
- Control of income/expenditure,
- Spare parts management, and
- Key performance indicator control.

Although CMMS software are tools to help solve problems, they cannot succeed at maintenance management problems. The general purposes of these software are listed as; maintenance status monitoring, control of sources, control of suitability for the targets of the company, safety, security and the inclusion of quality policies in the maintenance processes [28]. The ability to handle large amounts of data quickly in CMMS is crucial to managing the assets of organizations. Reports on statistics, highlighting key performance notes and troubleshooting provide the possibility of predicting for staff working on maintenance management [29].

The aim of this study is to determine the approximate date of upcoming failures of main engine and related subsystems by analyzing the information in CMMS without human factor. Although noteworthy defects, as a result of reports, notes and inspections, are prominent, they are not impressive in the planning stage considered as maintenance. The Artificial Neural Networks method has been preferred as it has eliminated the human factor due to its self-learning ability.

3. Material and Methodology

The historical development of maintenance systems and the expectations from these systems in industry and maritime transport have been summarized in part 2. By using a machine learning algorithm, Artificial Neural Networks (ANN), this research aims to have CMMS get the ability to estimate the upcoming failure. ANN demonstrates not only engineering, science and mathematics, but also exemplary applications in that it is good at the solution of medicine, business, finance and literature [30]. The selected method can provide the necessary modelling to the user without the need for any preliminary information and assumptions between input and output variables. For this reason, ANN has been preferred as the methodology for this study.

ANN is the realization of the learning function, the most basic feature of the human brain, by computer systems. The learning process is carried out with the help of examples. The network is formed by interconnecting of process elements called artificial neurons as shown in Figure 2. Each link has a weight value and the information that the artificial neural network processes is hidden in these weight values and spread to the network [31].

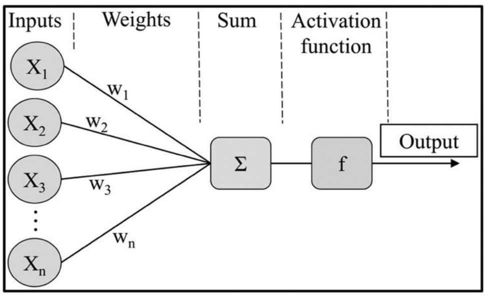

Figure 2: *Mathematical Model of Single Layer Artificial Neurons [32]*
Source: *Reorganized by the authors*

Each layer of the network includes the input vector, the weight matrix, the summation, the transfer function and the output vector. The elements in the input vector are connected to the neurons by their weight values. Each neuron involves the output vector, summation and transfer functions. In the creation of a neural network, the following three features should be considered [30]:

- Number of inputs,
- Number of neurons in output layer,
- Output layer transfer function

It is advised that a cycle be performed as shown in Figure 3, when it is expected to be a successful artificial neural network. All the processes starting from the Phase 1 have been carried out respectively, if the desired performance has not been reached, the operations at each step must be reviewed. The result of such a cycle through which the system inputs and parameters are reviewed and revised is unlikely to fail [33].

The most substantial feature that

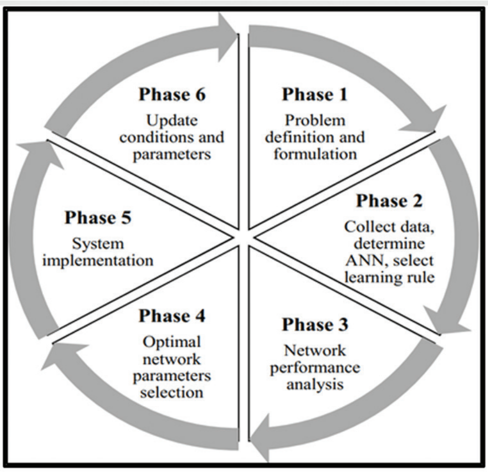

Figure 3: *Cycle of an ANN Project*
Source: *Composed by the authors*

distinguishes ANN is its ability to adapt to the medium that it is in. There is no specific standard in determining the structure of the network to be created and in selecting the network parameters. Because numerical information is the only input of the ANN, the time spent to finish the training is uncertain and the behavior of the network cannot be thoroughly defined so the need for expert users is inevitable [34]. ANN has in general pattern association, data clustering, learning statistical parameters and function approximation applications [35]. The fact that a well-trained network gives high-accurate results in different fields is one of the reasons that encourages the use of ANN.

4. Case Study

This study aims to predict equipment failures which are related to main engine and its auxiliary systems used in ships. A 10-year failure history has been used in this predictive study. The history has been recorded in a planned maintenance software, which has a type approve by DNV-GL for ISM code requirements. Maintenance record of the ship includes the components of the systems, the date of the failure and the maintenance process history. The components of the main engine and its subsystems belonging to the ship used here as the case ship have been used within the form of the output from the planned maintenance management software without any changes. Table 3 shows the above mentioned structure; there are 9 systems classified as main engine and its subsystems and 220 failures have been recorded in the last ten years. As a matter of confidentiality agreement, the information about the company and the ship, a container ship, is kept a confidential.

There are 47 components of the systems mentioned in Table 3. The names of the components, the system to which they belong, the component numbers, and the failure quantity of these components are shown in detail in Table 4.

The gathered failure data must be transformed into a matrix form in order to be transferred to the Artificial Neural Network tool used in the MATLAB® software. In Table 5 the component failures are indicated by 0-1 logic in Columns 1 to 47 which represents the components mentioned in Table 4. The records taken like time series based on "days" about the issue of "failures" have a value of "1" when there is any failure, and "0" when there is no failure. The day when the failure occurred is indicated in the last column. Because

Table 3: *Main Engine Related Systems and Failure Distributions*

System no	System Name	Failure Quantity	Percentage (%)
1	Air Charge System	8	3.6
2	Fuel System	48	21.8
3	Hydraulic System	1	0.5
4	Lubrication System	19	8.6
5	Main Engine	72	32.7
6	Cooling System	9	4.1
7	Exhaust System	24	10.9
8	Maneuver System	23	10.5
9	Starting System	16	7.3
	Total failure	220	100

Source: *Gathered by the authors*

Table 4: *Detailed Failure Distribution of the Components*

System name	***Comp. no***	***Comp. name***	***Failure number***	***System name***	***Comp. no***	***Comp. name***	***Failure number***
Air Charge System	105	Auxiliary blower	5	Main Engine	505	Oil mist	11
	110	Turbocharger	3		510	Piston ring	10
Fuel System	205	System failure	5		515	Cylinder cover	9
	210	Fuel pump top cover	2		520	Governor	5
	215	Viscometer	4		525	Main structural parts	12
	220	Water mist	1		530	Main engine block	6
	225	Fuel pump	20		535	Crankcase	2
	230	Fuel pump suction valve	3		540	Liner	2
	235	Fuel pump function valve	3		545	Connecting rod bearing	3
	240	Fuel injector	5		550	Crank pin	1
	245	Flowmeter	2		555	Main engine sensors	2
	250	High pressure fuel hose	1		560	Piston	9
	255	Fuel valves	1	Cooling System	605	Cooling oil	5
	260	Fuel non-return valves	1		610	Cylinder cover	2
Hydraulic System	305	Hydraulic System	1		615	Cooling water	1
Lubrication System	405	Alfa lubricator	5		620	Liner	1
	410	Lubrication pump	2	Exhaust System	705	Exhaust System	4
	415	Cylinder lubricator	7		710	Exhaust valve actuator	7
	420	Lubrication	5		715	Exhaust non-return valves	1
Maneuver System	805	Engine telegraph	9		720	Exhaust valves	12
	810	Control failure	10	Starting System	905	Starting air	6
	815	Maneuver system failure	2		910	Turning wheel motor	4
	820	System sensors	2		915	Auxiliary blower motor	2
					920	Starting system	4

Source: *Compiled by the authors*

the actual failure matrix size is 3630x48, a sample segment of the matrix is given short form in Table 5.

For a better understanding of the above table; an example can be given as follows: the cell value of the component 110 on the 169th day has “1”, because that day a fault occurred. On the 169th day, “0” is written to the cells belonging to the other components where no failure occurred. Since the planned maintenance system of the ship does not contain any failure record for two or more components on the same day, such a case is not included in the matrix.

The input data is compiled when the data in Table 4 is converted to the form of Table 5. The first two phases of the cycle are fulfilled up to this point. For Phase 3 and 4, the performance criteria of different networks should be compared, and the optimal results should be determined by heuristic approach. In Table 6, the key performance indicators are evaluated as "Mean Square Error", "Regression" and "Time". These indicators are compared with each other by "the number of the hidden neurons" and "the percentage of the data partitioning" values. When deciding on the optimal parameters, the Regression (R) and Mean Squared Error (MSE) values of the network trained by the Levenberg-Marquardt (LM) method are indicated in Table 6-8. The fact that the LM algorithm is intended for the ability of quick learning characteristic [30].

MSE is one of the performance parameters, the average squared difference between output and target values of the ANN. The lowest MSE values are preferred and “0” indicates zero error. Regression (R) measures the correlation between the output and the target, and it has a maximum value “1” meaning a close relationship, “0” is for random relationship [36]. The elapsed duration between the beginning of the training and the end of the simulation

Table 5: *ANN Failure Matrix*

105	110	205	210	...	915	920	Days
0	0	0	0	...	0	0	1
0	0	0	0	...	0	0	2
...	...	...	...	...	...	...	...
0	1	0	0	...	0	0	169
...	...	...	...	...	...	...	...
0	0	0	0	...	0	1	1189
...	...	...	...	...	...	...	...
0	0	0	0	...	0	0	3630

Source: *Compiled by the authors*

Table 6: *Performance Parameters and Data Partitioning (Training=60%, Validation=20%, Testing=20%)*

	Number of hidden neurons=10 and			Number of hidden neurons=25 and			Number of hidden neurons=40 and		
	Number of delays=2			Number of delays=2			Number of delays=2		
Performance values	Train.	Valid.	Test.	Train.	Valid.	Test.	Train.	Valid.	Test.
MSE	1062	19073	24800	0.197	5875	4569	411	9426	7924
Regression	0.999	0.991	0.988	0.999	0.997	0.997	0.999	0.995	0.996
Time	00:00:04			00:00:20			00:00:42		

Source: *Compiled by the authors*

***Table 7:** Performance Parameters and Data Partitioning (Training=70%, Validation=15%, Testing=15%)*

	Number of hidden neurons=10 and			**Number of hidden neurons=25 and**			**Number of hidden neurons=40 and**		
	Number of delays=2			**Number of delays=2**			**Number of delays=2**		
Performance values	Train.	Valid.	Test.	Train.	Valid.	Test.	Train.	Valid.	Test.
MSE	52	2268	30688	9.59	2301	6372	$7.4x10^{-9}$	4291	2930
Regression	0.999	0.999	0.986	0.999	0.999	0.997	0.999	0.998	0.998
Time	00:00:02			00:00:22			00:06:50		

***Source:** Compiled by the authors*

***Table 8:** Performance Parameters and Data Partitioning (Training=80%, Validation=10%, Testing=10%)*

	Number of hidden neurons=10 and			**Number of hidden neurons=25 and**			**Number of hidden neurons=40 and**		
	Number of delays=2			**Number of delays=2**			**Number of delays=2**		
Performance values	Train.	Valid.	Test.	Train.	Valid.	Test.	Train.	Valid.	Test.
MSE	0.152	464	15983	$6.8x10^{-5}$	453	10603	**1.34**	**2449**	**629**
Regression	0.999	0.998	0.992	0.999	0.999	0.995	**0.999**	**0.998**	**0.999**
Time	00:00:02			00:00:27			**00:00:46**		

***Source:** Compiled by the authors*

of the network is given as 'Time' variable. The comparison of MSE, R and Time values of the simulated networks are indicated in Table 6-8. The optimal parameters are determined as 40 hidden neurons and 2 delay time such as the partitioning of the data in Table 8 (Training=80%, Validation=10%, Testing=10%).

5. Results and Findings

The planned maintenance and failure history of a ship is the most significant point in the technical and administrative management of ship operations. Manufacturers use the failure data of their test devices and the products they sell while preparing the planned inspection and maintenance programs. However, the equipment on the ship's main engine and its connected systems is not only used in the ship but also in different places in the industry. Therefore, there is a problem in ability to identify the failures that trigger one another in different combinations of the systems. The test assemblies of these combinations should be carried out separately, to conduct more proper reliability analysis of the equipment, but no such system exists yet. This once again brings the importance of feedback mechanism. The ANN simulation results have been gathered in Table 9.

The timeline in Figure 4 is formed to provide a more comprehensive view of the predicted values shown in Table 9. The bias value between the start of timeline and the end of the recorded date is emerged from ANN prediction method errors. This error is around 2% and is within the acceptable limits. However, the main issue to be concerned in this study is the sequence of failures and time difference between the malfunctions. According to the research, if personnel in charge of the maintenance has a procedure at hand like the one in Table 4, a better practice will be carried out when any personnel starts the maintenance process from beginning of the timeline.

Table 9: *The Past and Predicted Failure Days of the Components*

Comp. no	The days of past the failures	Predicted failure
105	119, 367, 2916, 2929, 3378	3638
110	169, 1465, 1495	3647
205	1029, 3431, 3449, 3568, 3627	3584
210	3120, 3319	3734
215	1107, 3071, 3401, 3608	3610
220	2967	3612
225	252, 362, 429, 567, 1072, 1084, 1085, 2331, 2618, 2671, 2690, 2916, 2957, 3121, 3202, 3221, 3227, 3232, 3289, 3563	3606
230	2691, 3328, 3505	3629
235	3063, 3109, 3185	3628
240	187, 668, 1059, 2380, 2600	3630
245	2608, 3195	3747
250	2296	3653
255	2598	3766
260	1510	3640
305	1579	3625
405	2781, 2910, 2949, 3044, 3237	3658
410	3200, 3226	3653
415	1059, 1243, 1247, 1249, 1266, 2359, 3412	3647
420	2523, 2602, 2945, 2975, 3615	3610
505	2576, 2583, 2965, 2979, 2985, 3107, 3219, 3246, 3288, 3345, 3458	3607
510	1463, 1809, 1810, 2578, 2596, 3014, 3178, 3192, 3252, 3344	3634
515	2267, 2870, 2887, 3002, 3124, 3172, 3198, 3272, 3395	3669
520	956, 2677, 2830, 2907, 3459	3634
525	929, 1501, 2445, 2470, 2472, 2567, 2694, 2696, 2812, 2838, 2840, 3129	3751
530	967, 974, 1467, 2120, 2608, 3076	3692
535	2711, 3624	3582
540	1688, 3298	3612
545	1579, 2504, 2505	3629
550	992	3592
555	1, 2478	3654
560	2500, 2596, 2597, 2934, 2981, 2987, 3095, 3141, 3353	3663
605	2969, 3327, 3343, 3364, 3629	3672
610	2627, 2699	3565
615	3579	3633
620	3332	3652
705	401, 1259, 3058, 3400	3595

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Table 9: *The Past and Predicted Failure Days of the Components* ***(cont.)***

Comp. no	The days of past the failures	Predicted failure
710	1316, 1318, 1370, 1616, 2811, 3326, 3610	3637
715	401	3647
720	297, 2296, 2614, 2781, 2826, 3164, 3195, 3216, 3459, 3475, 3507, 3551	3620
805	2237, 2465, 3169, 3325, 3361, 3381, 3451, 3542, 3564	3694
810	1257, 1417, 1579, 1666, 3010, 3389, 3509, 3586, 3609, 3611	3674
815	3339, 3627	3697
820	3485, 3592	3637
905	98, 2216, 2465, 2806, 3453, 3493	3637
910	2539, 2788, 3111, 3364	3657
915	3459, 3462	3644
920	1189, 1280, 1416, 3579	3611

Source: *Compiled by the authors*

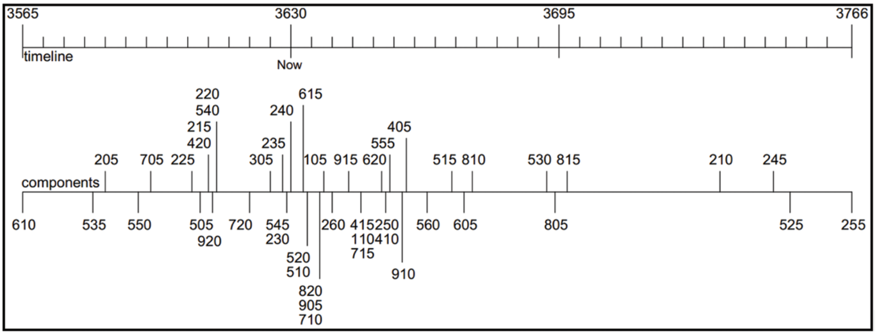

Figure 4: *Failure Timeline of the Components*
Source: *Composed by the authors*

6. Conclusion and Discussions

Repair and maintenance is a critical technical issue for ships. Although the equipment of ship is covered by planned maintenance, failures may occur due to their physical conditions. The overall condition of the ship is considered when planning maintenance and navigation. When a significant disruption and damaging situation of vessels with maintenance systems is investigated, it is understood that poor systems result in serious deterioration in safety, efficiency and environmental performance. Planned maintenance systems include extensive and periodic maintenance processes for systems and components. A PMS is organized by the shipping or the ship-owner company that is related to the requirements of the manufacturers, operators, management policy of the company and the ship classification societies. These systems have also strengths, weaknesses, conveniences and challenges. The PMS concept, when integrated into the safety management system, contributes significantly to strengthening the system performance and reliability.

When presumptions about future failures are known; maintenance, condition monitoring, necessary spare part orders can be reorganized. In addition, important information can be obtained to update daily, weekly, monthly or working hours based maintenance processes in the PMS. Similar studies on this subject offer different approaches to eliminate the worst cases. Dikis et al. [22] suggested a MRA methodology by reviewing the requests of existing CM systems. Dynamic (time-dependent) operating cases at the system, subsystem and component level were evaluated on the basis of reliability performance measurement, including various failure modes and failure case scenarios for the turbocharger and cargo pump. In order to test the requested methodology, the idea of installing an alarm and warning system in practice was proposed in the future study of Dikis et al. For a similar purpose, Isa et al. [21] conducted research to obtain highly reliable data and to plan better maintenance to prevent the destructive failures and expensive component changes of the main engines, generators and gearboxes of a commercial ship. Isa et al assert that particle size over 50 μm indicates abnormal wear. Since the presence of these particles will cause the lubrication system to not operate efficiently and also the parts of the metallic components to be destroyed, urgent maintenance is recommended in the equipment if this situation is observed. Gkerekos et al. [23], tried to predict the occurrence of malfunction by detecting abnormal vibrations in the ship's main engine. The model conducted under two stage; data storage and anomaly detection. That case study demonstrated that Support Vector Machines (SVM) are the accurate models for machinery fault detection. The development of the anomaly detector/ classifier has been proposed in further study so that the discernment between different faults is possible. In this way, a Decision Support System provides guidance with regards to the selection of optimal maintenance actions. The main purpose of similar studies is that the causes of failures are not concerned, although the prediction of faulty component and the date of upcoming machinery failure is the most significant issue for the management of a sound maintenance plan. Comparing the two hybrid MCDM techniques, Emovon et al. [24] concluded that the "safety" factor has 50% of the total compared to all other criteria in the selection of maintenance techniques to be applied to ship machinery and equipment. It was concluded that the condition-based maintenance is the best-ranked maintenance strategy for the high pressure pump of the fuel oil system of the marine diesel engine. It was also emphasized that the transition from corrective maintenance and time-based preventive approaches to a safer and more reliable maintenance approach for any critical equipment belonging to a system. Lazakis et al. [25] claims that FMEA and FTA tools are complementary to each other and it is necessary to monitor the physical parameters as well as to determine the possible causes and effects of critical system failures. The use of ANN stems from the need to make time-series analysis of physical parameters. Based on past and current fault data, it is argued that diagnostic and performance measurement will contribute to the development of a sound maintenance strategy. It is also recommended to determine the critical deviations from the threshold value of the equipment and to identify those exceeding this threshold by the warning system in the future study.

The aim of this study is to predict which equipment will fail in the predicted future, using recorded failure data. The most striking feature of this predictive method is that the components in the system can provide different maintenance methods according to the failure paths.

Artificial Neural Networks method, which is frequently used for predictive maintenance in the literature, has been adopted. The network was trained with the history of the failure data, and so the trained network was utilized as for the upcoming failures. The result of the analysis in Table 9 is for the end of 3630th day. Even after one day all these calculations must be repeated. The reason is that a new row of data has been added to the recorded failure data given in Table 5. To ensure precise predictions, the organized ANN model have to include the failure data obtained after 3630th day, and the model should be re-trained with new record. If the predictions wanted to be done continuously by artificially, the obtained future failure data for each day should be added in Table 5 and all the training and simulation stages must be iterated progressively. Otherwise, it is not conceivable to ask for a failure estimation from a static system.

In the operational phase, the diagnosis and upgrade processes are carried out based on the condition monitoring parameters integrated with the experience of the maintenance services. An optimized and predictable maintenance system is a guide for operators. If you believe that you employ experienced personnel, and support the staff with a system that works properly and makes accurate predictions, the first step in sound maintenance management will be taken. A successive progress will be taken to prevent possible malfunctions when the modeled ANN in a future study can be revised to provide desired software continuity. Taking into account security, economy and system integrity; spare parts, time, personnel and organizational planning required for maintenance application will be provided by this methodology.

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Frustration-Aggression-Theory Approach Assessment of sea Piracy and Armed Robbery in Nigerian Industrial Trawler Fishery Sub-Sector of the Blue Economy

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ABSTRACT

The study analyzed the economic cost of output losses as a result of death and injury occasioned by maritime piracy and armed robbery in the ocean trawler fishery sub-sector of Nigeria and the global maritime industry; as economic justification and catalyst for public-private-partnership in reversing the trend of frustration induced aggression of piracy, against the maritime industry in the Atlantic coast of West Africa and Nigeria, through investment in human capital development, youth employment, poverty eradication and community development programmes in the coastal communities of Nigeria. It employed historical design approach where secondary data was obtained and analyzed using the Gross Output Model and the empirical probability model to determine the output losses due to death and injuries to human capital occasioned by pirate attacks in the maritime industry. The empirical probabilities of risks of death, injury, kidnap for ransom, assault, missing of crew, hostage taking of crew and threats of death were also determined. An estimation model was developed to estimate output losses due to death, injury, etc; based on the relationship between the empirical probability coefficients of each risk type, the per capital output of the economy and the number of maritime workers exposed to pirate attacks over a given period in any economy. Public-private participation in development of coastal communities, youth employment, poverty eradication and youth entrepreneurial development programmes was recommended as a long-term solution to frustration induced violence of pirate attacks in Nigeria and the Atlantic coast of West Africa.

Keywords

Frustration-aggression, Piracy-and-armed-robbery, Trawler-fishery, Blue-economy.

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1. Introduction

The blue economy of Nigeria which depicts her ocean economy is composed of the various ocean economic business variables and resources, constituting sources of revenue and economic livewire of the nation. According to reference [1], coastal governance index scores of world coastal economies put South Africa in the ninth, and Nigeria in the nineteenth place among world's 20 best economies based on the huge potentials of the blue economies of the nations. A study on the contributions of the blue economy of West African States identified crude oil, natural gas (both ocean energy), diamond, gold, fisheries, marine biotechnology, marine tourism, maritime transport and shipping, as major components of the West African blue economy, contributing paramount incomes to the economic prosperity of the region [1]. In Nigeria for example as a dominator of the maritime affairs of West African States, offshore oil and gas exploration and production constitute a major contributor to national income with duties generated from shipping import and export trade constituting the second largest revenue earner to the nation. Other ocean and/or blue economy business variables such as the ocean fishery sub-sector, inland water transport, downstream oil refining, etc. also contribute as economic drivers of the West African state. Results of studies in Nigeria show that the industrial fishery sub-sector, shipping and oil and gas offshore energy sectors of the blue economy contributes aggregate average GDP of 3301001.0633 billion naira per annum to the national output [1]. The study notes that the industrial trawler fishery sub-sector contributes far less than ocean energy and shipping, such that the yield of the ocean economy is skewed in favour of ocean energy and shipping business operations. The evidence suggests that the productivity of the industrial fishery business sub-sector is dwindling despite huge private sector investments in the sector and the potentials of growth cum enormous economic expectations from the sub-sector.

Recent outcry by Nigerian Industrial Trawler Owners Association (NITOA) lamenting the huge revenue losses faced by the operators occasioned by violent attacks by sea pirates lend support to earlier public opinion that the industrial fishery sub-sector over the years faced the challenges posed by pirate attack against ships in the Atlantic coast of west Africa, more than the shipping and ocean energy sub-sectors. Statistics by [2] and [3] reveal that piracy attacks against fishing vessels in Nigerian domain of the Gulf of Guinea (GOG) is responsible for the decline in the yield and financial losses in the sub-sector and its contribution as major component business operation of the blue economy of Nigeria. See figure below for further insight into the trend of direct financial losses occasioned by piracy and sea robbery attacks on the industrial fishery sector of Nigeria.

While the direct financial losses to the sub-sector are as shown in Figure1 above, the indirect losses occasioned by output losses to the society as a result of injuries and deaths suffered by fishing crew need to be estimated as basis for economic justification to investment in programmes and policies for the fight against piracy

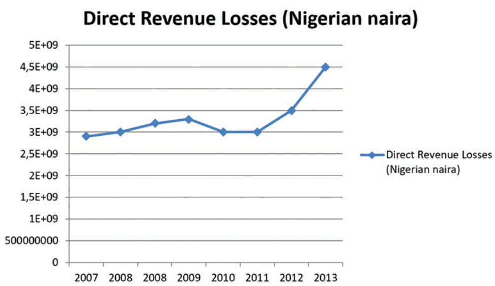

Figure 1: *Direct Revenue Losses by the Nigerian Industrial Trawler Fishery Sub-sector Occasioned by Pirate Attacks.*
Source: *Authors presentation based on NITOA statistics*

and sea robbery in the west coast of Africa. See Figure2 below for the trends of pirate attacks and the associated deaths of fishing crew members in the industrial fishing sub-sector of the Nigerian blue economy.

An inquiry into the phenomenon of piracy in the Atlantic Coast of West Africa, expressed by reference [4] as constituting high level threats of violence and aggression to security in the waters of West Africa, especially in the coastal communities in Nigeria; defining it according to the International Maritime Bureau [5] as "an act of boarding or attempting to board any ship with the apparent intent to commit theft or any other crime and with the intent or capability to use force in the furtherance of that act". The connotation that piracy and armed robbery against ship denotes both attacks actual or attempted irrespective of the position of the vessel at the point of the attack: at sea, within the coastal or inland waters, within the seaport and anchorages or at dock; support the assertion by public opinion that it is an act of youth aggression, anger and/or violence in the coastal communities in Nigeria and the West African coastal communities, in the drive to illegitimately and forcefully benefit from the profitable maritime business operations in their communities; but for which they have the general perception that they have benefited little or nothing from. Its explanation can thus be analyzed

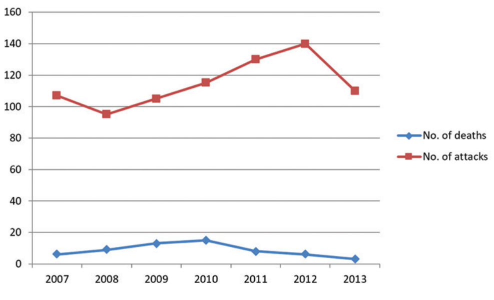

Figure 2: *Trend of Pirate Attacks and the Associated Deaths of Fishing Crew in the Nigerian Industrial Trawler Fishery Sub-sector.*
Source: *Authors prepared pictographic*

in the light of the Frustration-aggression Theory (FAT) proposed by Dollard, et al. in 1939 and further developed by Neal Miller in 1941 and Leonard Berkowitz in (1969). The proposition of the FAT is that aggression results from frustrating or blocking an individual's effort to legitimately attain a goal. The work of [6] supports the position of the FAT by hypothesizing that human frustration may lead to aggressive behavior and/or violence. According reference [6], frustration ultimately leads to aggression and aggression always implies that frustration has occurred at some previous times. The theory suggests that individuals become aggressive when there are obstacles blocking their legitimate drive to fulfill target goals and objectives. In the views of [7], aggression is a human behavior intended to harm another person who does not want to be harmed. This is exactly the case in the coastal communities in Nigeria where private ship operators are attacked for government negligence in providing care (employment, social welfare, quality education, modern healthcare facilities) for the society and the youth in particular. For example, the trend of revenue generation to the central government and contribution to the national GDP from maritime business operations such as ocean energy, maritime transport and shipping, industrial trawler fishery, etc. which have the coastal communities as hosts is increasing significantly over the years, but the standard of living, youth employment statistics, revenue allocation for coastal community development and poverty index shows negligible non-significant improvement and/or declining trend in most cases, even in the face of increasing youth population [8]. See Table 2 following page.

The table indicates the percentages of youth unemployment rates in the coastal communities and states defined by United Nations Development Programme [8] as the percentage of youth aged between

Table 1: *Youth Unemployment and Underemployment Rates in Selected Coastal States in Nigeria*

Coastal States	% of Youth Unemployment	% of Youth Underemployment
Akwa Ibom	11.3	33.7
Bayelsa	6.8	19.4
Cross River	1.8	12.0
Delta	9.3	29.2
Rivers	11.4	25.3

Source: *Nigeria National Bureau of Statistics*

15 to 34 years willing and ready to work; seeking for employment opportunities but could not find any. This is exclusive of youth who are doing fulltime studies in schools and are not seeking employment as such. The reality in the region however is that there is the preponderance of adults with ages above 35 to 40 years who are willing to work but who have never had the opportunity of being gainfully employed for the first time ever. Yet, this group watch and see the multinational oil , gas and other maritime companies tapping the natural resources in the communities posting millions of dollars of profits annually while government officials are spending petro dollars corruptly gotten from the resources of these coastal communities. The table below evidences the size and categorization of youth population of some selected coastal states in Nigeria.

The size of the youth population in relation to the aforementioned employment rates gives a clearer picture of the youth population that is either unemployed or underemployed. In analyzing the issue of youth violence in the Niger Delta, reference [9] classified the youth population in the coastal states of the Niger Delta into three as follows:

(1) Youths actively agitating for their rights of good living conditions and restoration of the dignity of coastal communities of the coastal states genuinely;

(2) Youths on a deliberate mission to avenge the perceived betrayals of the coastal communities by elites in the region who are seen to have betrayed the youth for abandoning the struggle for the improvement of living standards in the region.

(3) Youths engaged in criminal activities by their very natural disposition.

Reference[9] notes that while the first youth group are averse to the current state of affairs and queries their current socio-economic situation; and agitate that government should provide solutions to continued poor state of living, unemployment, poverty, environmental degradation, lack of basic social amenities, and infrastructures, etc. They seek to engage the government to provide genuine solutions to their problems but the tool

Table 2: *Age Composition of Selected Coastal States' Youth Population in Nigeria*

Age Categories	AKWA IBOM	BAYELSA	DELTA	RIVERS
15 -19	458,814	199,148	471,245	604,685
20-24	388,866	167,662	418,609	549,285
25-29	336,925	146,861	357,452	486,825
30-34	260,231	116,574	272,878	376,281
total	1,444,836	630,245	1,520,184	2,017,076

Source: *Nigeria National Bureau of Statistics* for getting government attention is in most times violence or civil disruption [9]. They are forced to adopt the strategy of the natural criminals of group three such that each youth group metamorphoses into an aggressive violent group attacking investments and human resources in the coastal states.

The poverty trend in the coastal states is a further motivational factor pushing younger people into early preparation for violence, criminality and attacks against the activities of the multinationals and other maritime companies in the regions. This is after the sad experience of having seen the peaceful elderly lead a helplessly poor lifestyle which is a bad plight in comparison to the flamboyant and opulent lifestyles of the aggressive and violent militant and pirate groups. See the table below for the trend in poverty in some selected coastal states in Nigeria.

The table shows that all the coastal states making up the Niger Delta region had less numbers of poor people or poverty rate in 1980 but fell steeply deep into poverty as time progressed and has remained in it even in the face of increasing revenue earnings from the ocean energy operations and other maritime business activities. The Human Development Index (HDI) in the coastal communities in the Niger Delta region of Nigeria according [8] is 0.564. This is significantly less than that of countries and coastal regions having similar ocean energy reserve of oil and gas resources. For example, the HDI of Venezuela and Indonesia are 0.772 and 0.697, respectively [8]. UNDP also notes that the high prices of commodities within the coastal communities which limit purchasing power of low income earners induced by the high salaries paid to the employees of the oil and gas multinationals who may not

Table 3: *Trends in Poverty in selected Coastal States in Nigeria (1980-2004)*

Coastal state	1980%	1985%	1992%	1996%	2004%
Ondo	24.9	47.3	46.6	71.6	42.15
Rivers/bayelsa	7.2	44.4	43.4	44.3	29.09
Edo/delta	19.8	52.4	33.9	56.1	45.35
Cross River	10.2	41.9	45.5	66.9	41.61

Source: *National Bureau of Statistics*

Table 4: *Fiscal Centralization of Proceeds from Ocean Energy to Federal and State Governments*

Years	% share to coastal oil producing state governments	% share to Federal Government in Abuja
1960-67	50	50
1967- 1969	50	50
1969-71	45	55
1971-75	45 less proceeds from offshore	55 in addition to proceeds from offshore
1975-79	20 less proceeds from offshore	80 in addition to proceeds from offshore
1979-81	-	100
1982-92	1.5	98.5
1992-99	3	97
1999-	13	87

Source: *Adapted from UNDP Report (2006).*

even be from the host communities but reside within. This fiscally incapacitates the unemployed youth in the coastal communities from being able to adequately settle the costs of basic needs of housing, healthcare, transportation, education etc., thus making the scourge of poverty more felt [8]. Reference [9] traced the source of poverty in the Niger Delta and coastal communities to Federal Government's intentional deprivation of the coastal states and communities of the rights to the tapping of the resources found in their soil and skewed oil revenue sharing formula devised by the Federal government to starve the coastal communities of the revenue generated in their communities. See the table below for further insight into how the revenue sharing formula is seen as aiding further frustration and impoverishment of the coastal communities and states.

A perusal of the above table shows the fiscal deprivation of the coastal communities of proceeds from the resources in their communities and its centralization in the hand of the Federal and state governments who corruptly embezzle it without any form of developmental plan or investment in the human capital in the coastal zones. It equally shows that between the 1960s and 1971, the coastal states governments got between 50% -45% of the fiscal proceeds from the resources in the coastal states and by 1975 to 1980 got only about 20% while the Federal government took the rest 80% plus proceeds from offshore operations. When compared with the poverty data, we may rightly infer that the coastal states experienced less poverty and had less number of poor populations in the pre 1980 years up to 1980 when the coastal state governments were in control of the resources and earn a fair percentage of the fiscal proceeds from the maritime business operations. The post 1980 years particularly in 1981 which marked the period that the Federal Government took hundred percent (100%) share of all proceeds from resources in the coastal communities and subsequent release to the communities of 1.5% (1982-1992) and a paltry 3% (1992 -1999) to the coastal states increased the trend of poverty incidence in the Niger Delta coastal communities and subsequently the frustration of the people living in the coastal communities. It's clear from the above table that the oil bearing coastal communities who lost their natural sources of employment (primarily fishing and agriculture) to the activities of multinational oil and gas companies were never considered in the sharing of the revenue proceeds from the resources under their soil. No developmental plan whatsoever was planned for coastal oil bearing communities while there exist development plans for other cities contributing nothing to the Federation account with proceeds from the coastal communities [10].

A feeling of fiscal deprivation possibly led to frustration, aggression and the violent demand by youths for a fair share of the resources from the region which now manifests as piracy and sea robbery as a backlash effect of the fiscal deprivation and poverty suffered by the coastal communities in Nigeria. A sight of the housing and living pattern in the coastal communities of Nigeria evidences further the incidence of poverty and deprivation. See Figure 3 below.

Figure 3: *Common Housing Pattern in Typical Niger Delta Coastal Communities in Nigeria.*
Source: *Adapted from UNDP report, (2006)*

Figure 4: *Common Toilet House Found in Most Coastal Communities in the Niger Delta.*
Source: *Adapted from UNDP report, (2006)*

Examining the piracy and armed robbery attacks against the industrial fishery sub-sector in the GOG and Nigeria maritime domain which constitute a major act of aggression and violence induced by the unrelenting drive by the youth of the coastal states and communities to derive economic gains from the business activities and operations in their maritime domain in a bid to escape the pang of poverty; the frustration-aggression theory (FAT) becomes a perfect explanation of the violence and attack against the ocean fishery industry by the youths of the coastal states in Nigeria in particular and the GOG states in general. The work of reference [11] notes that some of the youth involved in acts of violence and aggression against safe maritime operations have in the past risen to become prominent political actors, leaders and men of affluence in the region with connections to high ranking security personnel, politicians and government officials. The later fact becomes a motivating factor for younger youth to tow the line of piracy and aggression against maritime operators as the only avenue for economic advancement and escape from poverty.

For example, references [12] and [13] note that the recent upsurge in violence and pirate attacks in Nigeria industrial Fisheries sub-sector no doubt has profound negative effect in capacity building and development of the trawler fishery sub-sector. They harp on the fact that the sector continues to lose lives of fishing crew, valuable equipment, vessels, and fishery products and revenue. Reference [13] and [2] valued the fishery products lost to violence of piracy and armed robber against fishing vessels over a period less than four years at over three billion (3billion) naira with overall losses of all components valued at Twenty billion (20 billion) naira in less than four years. IT is important to also state that the acts of piracy and sea robbery aggression against the fishery sector has left many members of onboard crew dead while some are permanently disabled with the negative multiplier effect on the Nigerian society. It is therefore necessary that an empirically determined solution strategy be developed taking into consideration the propositions of the FAT. In order words, to reverse the trend of revenue losses, human capital and equipment losses by the sub-sector; it will require a reversal of the trend, propensity and/or density of aggressive acts of piracy and armed robbery attacks against the sub-sector. To justify economic investments in human capital development in the region and catalyze stakeholders into the action of reversing it; the trends and magnitude of economic losses and the probabilities of loss, death, injury and kidnap etc., need to be empirical and holistically determined. As mentioned above, many studies have estimated the costs of piracy in different regions of the world including Nigeria but such an estimate failed to determine also the output losses associated with crew (human capital) deaths and injuries occasioned by pirate attacks in the waters of Nigerian maritime. This is a component part of the aggregate cost of maritime piracy needed as catalytic information for stakeholders to take remedial action against sea piracy in Nigeria based on the propositions of FAT. These form the central challenges which the study is cast to address.

2. Objectives of the Study

The aim of the study is to analyze the challenges of piracy and sea robbery attacks against the industrial trawler fishery sub-sector in Nigeria based on the frustration-aggression theory with a view to provide empirical economic loss information as justification for investment in human capital development in and employment in the coastal communities and for development of short and long term strategic solutions to the aggressive acts of piracy and sea robbery in Nigerian waters.

Other objectives are:

(i) To estimate the output losses occasioned by fatal pirate attacks against industrial trawler fishery sub-sector in Nigeria between 2006 -2013.

(ii) To determine the output losses as a result death and crew injury occasioned by pirate attacks in the global maritime industry between 2006 -2018.

(iii) To measure the empirical probability coefficient of fatal pirate attack against the industrial trawler fishery sub-sector.

(iv) To estimate the empirical probability coefficients of piracy induced risks of death, crew injury, kidnapping for ransom, missing, assault, hostage taking and death threats in the global maritime industry.

3. Brief Review of Literature

In Nigeria, the ocean economy holds enormous potentials of growth and has remained the major sources of revenue to the nation. The exploitation of the ocean resources in the coastal communities in Nigeria, particularly in the Niger Delta region has however caused the inhabitants of the region who originally were predominantly farmers and fishermen to lose their original sources of livelihood to the massive exploration and exploitation activities in the region [1]. The quantum of new jobs created by the new multinationals involved in the harnessing of the ocean economy is continually inadequate compared to the number of unemployed youth yearning for gainful employment opportunities to fulfill their life goals.

Corruption too has made it impossible for the Government to re-invest adequately the proceeds from the ocean economy in the region in order to gainfully engage the unemployed youth. It can be inferred based on the aforementioned fact that the youth of the region is frustrated; seeing the near incapacity, un-readiness and refusal of the Government to use the proceeds from the ocean economy of the region to enhance the capacity of the youth to legitimately achieve their life goals via education and gainful employment [3]. By the propositions of FAT, Frustration precedes aggression while aggressive and violent behavior is the offshoot and brain child of frustration. It is believed that the Nigeria Government and the State Governments of the various coastal states made a clear choice of blocking the youth of the communities from legitimately reaching their goals by the continued underdevelopment of the coastal states and mostly by high level of graduate unemployment. In reacting to the frustration and blockade to legitimate achievement of life goals, the youth of the coastal states tend to have reacted aggressively through acts of violence, piracy and armed robbery against the maritime industry, having been well convinced that the maritime and blue economy holds the potentials to surely meet their needs of evolving from starvation, hunger, unemployment, etc., and ensure their economic emancipation. Unfortunately, all the sub-sectors of the ocean economy have suffered economically and socially, having been negatively impacted by the acts of piracy, terrorism and sea robbery; the industrial trawler fishery sub-sector seem to be the only organized group who have over the years been able to determine the quantum of direct financial losses the sub-sector has suffered and made it a public knowledge. Thus the perception that the sub-sector has suffered the effects of piracy in Nigerian waters most over the years. For example, the ocean beyond piracy estimated the global aggregate macroeconomic cost of maritime piracy in the economies of different regions in 2010 alone at $1.25billion. See Table 5 below for regional macroeconomic costs of piracy [5].

The report estimated the total global cost of piracy including cost of ransom paid for kidnapped crew, insurance, security equipment etc. to be between $7 billion to $12billion per year. See Table6 below for disaggregated cost of piracy on the global economy in 2010 alone.

The viewpoint echoed by many public opinion analysts is that the quest for freedom from economic strangulation by the coastal communities is a serious protest against criminal neglect, marginalization, oppression and environmental degradation cum socio-economic hopelessness and in one word, frustration in the coastal communities [3]. There is multiplicity of evidence in literature linking the piracy and sea robbery attacks against ships in the coastal communities to multiple unaddressed deprivations and grievances by the people in the coastal communities caused by the government.

Unluckily, investments in the industrial trawler fishery sub-sector which are largely indigenous private sector investments aimed at harnessing the potentials of the Nigeria wide fishery resources is mostly affected by this frustration-aggression induced piracy, sea robbery and violence in the Nigeria maritime domain of the GOG. The Nigeria industrial trawler fishery industry represents the fleet of commercial

***Table 5:** Macroeconomic Cost of Piracy in 2010 Alone*

Country	Cost Factor Categories	USD Lost Per Annum '000,000
Egypt	Revenue Losses due to use of Suez canal fees as against use of Gulf of Aden	642
Kenya	Impact on Trade	414
Yemen	Impact on Trade	150
Nigeria	Financial Losses by Oil and Fishing Industry	42
Sychelles	Financial Losses by Fishing and Tourism Industry	6
Total		1.25 billion

***Source:** Adapted from Ocean beyond piracy Reports (2010).*

***Table 6:** Total Estimated Disaggregated Cost of Piracy in 2010*

Cost factor	Cost ($)
Ransoms	$148 million
Insurance Premiums	$460 million to $3.2 billion
Re-Routing Ships	$2.4 to $3 billion
Security Equipment	$367 million to $ 2.5 billion
Naval Forces	$2 billion
Prosecutions	$31 billion
Anti-Robbery Organizations	$19.5 billion
Cost to Regional Economies	$1.25 billion
Total Estimated Cost	$7 to $12 billion per years

***Source:** Adapted from www.oceansbeyondpiracy.org (2010 piracy report)* motorized fishing vessels (trawler) employed in the wide ocean fishery sub-sector in Nigeria. It encompasses all the fishing trawlers owned and registered by members of the Nigerian Industrial Trawler Owners Association (NITOA) with which wide fishery resources in the Nigeria coastal and territorial waters is being harvested. The ocean fishery sub-sector is believed to be a very important sector of the nation's blue economy, contributing meaningfully to the GDP of Nigeria and overall economic growth [2]. However, the menace of youth aggression and violence in the coastal communities in the maritime domain evidenced by widespread acts of piracy and armed robbery against ships in the Nigeria maritime domain in particular and West African coast in general has direct delectation effect on the productivity, capital base, and general life of the industrial trawler fishery sub-sector as well as impinge on the ability of the sub-sector to supply fishery resources and employment for the economic wellbeing of Nigerians. Sustainable growth and development cannot be achieved in the drive to harness the blue economy and wide fishery resources of the region in the face of piracy, youth violence and aggression against indigenous fishing interests. Reference(14] notes that the consequences of the attacks is that the Atlantic coast of West Africa and Nigeria become a significant element in the security make up in Africa. Maritime insecurity is on the rise with the associated instabilities with wide range of socio-economic implications. According to [14], apart from the challenges of sea crimes and violence posed by this, maritime insecurity also impacts on livelihoods, cultures, histories, and social identities of coastal states who have the sovereign rights to maintenance of safe and secured waterways. Other consequences identified by [14] include challenges of environmental pollution and degradation, economic distortions widespread social anomie in the coastal states and communities. Reference [15] opines that piracy in the Gulf of Aden for example causes disruption in relation to the overall volume of world seaborne trade. The study however notes that piracy in the Atlantic coast of West Africa has capacity to cause major disruption in global fossil energy supply and that will affect cost of global production and supply [15]. Moreover, piracy has led to the loss of particular shipping routes as vessel has to now bear the cost of routing ships particularly via canals. While many available literature in the study of piracy in the Atlantic Coast of West Africa center on measuring the direct revenue losses occasioned by it, trend and severity of attacks, issues of kidnap of expatriate workers for ransom, etc [16].

There exist literature gaps such that the output losses to the society associated with deaths of crew members and injury to crew members using the GOM of the HCM and/or other methods seems largely unavailable. Providing these evidences will aid in providing empirical justification for investment in maritime security programmes and policies in Nigeria and the Atlantic cost of West Africa.

4. Materials and Methods

Secondary data was obtained from the ICC International Maritime Bureau and the Nigerian Industrial Trawler Owners Association (NITOA) on the frequency and severity of pirate attacks against fishing vessels operating in the Nigeria maritime domain in the GOG covering a 13 year and 7-year periods of global and Nigeria attacks, respectively. Data on output per capital covering the same period (2006 -2018) was also obtained from the World bank reports. The Gross Output model (GOM) of the human capital model (HCM) used by World health Organization [17] for valuing human life was adopted and used to estimate the economic cost of fatal and injury pirate attacks against fishing crew in Nigeria and the global maritime industry. According to the theory, the cost of death is not less than the loss of output which the victim of fatal attack would have contributed to the economy if alive. Similarly, the economic cost of injury is not less than the loss of output which the injured would have produced over the period of hospitalization/injury induced idle time/downtime. Reference [17] notes that valuing the economic cost of death of fatal incident victims by the human capital approach involves taking the discounted value of people killed in attack, since the loss of output is related to the nation.

By the Gross output model (GOM), life is valued as the total discounted value of the expected output and/or per capita output. Thus the value of the gross output represents expected economic benefit to the economy from saving a life in a fatal pirate attack or preventing an injury using security shields against aggressions of maritime piracy, violence and sea robbery.

For a fatal pirate attack involving death the economic cost of output lost per death is given as;

$$P_N = Y\left[\frac{1}{i}\right]\left[1 - \frac{1}{(1+i)^t}\right] \quad (1)$$

$$\text{Total output lost for several deaths} = P_T = Y\left(\frac{1}{i}\right)\left(1 - \frac{1}{(1+i)^t}\right)N \quad (2)$$

PN = National output forgone per death due to pirate attack.

PT = Total output forgone due to fatal attack involving more than a death.

Y = Average (national) output or per capital output.

i = is the social rate of discount (interest) which for developing countries tends towards 10 to 12 according to World bank records.

t = is the number of working years lost per fatality, defined as retirement age in public sector less national average age of fatality for developing countries, tends towards 25.2 to 29 years. For injury whose hospitalization period is one years as used in the period, t=1.

N = total number of death in fatal attack over a period of time.

Using the method described above and the secondary data on fatal pirate attacks and injury to crew obtained; the output losses occasioned by maritime piracy induced crew deaths and injury was estimated.

4.1. Probability Theory

Furthermore, we used the empirical probability measure which is an offshoot of the probability theory used by [18] and [19] to determine the empirical probability of risks associated with pirate attacks against ships. The idea is to measure the magnitude and likelihood of risks of injury, death/killing of crew members, kidnap for ransom, assault, missing of crew members, hostage taking and threats to life in relation to the number of seafarers/maritime workers exposed to pirate attacks. The Probability theory deals with the chance or stochastic process also referred to as a random process. Probability is a ratio that measures the uncertainty that some events will occur based on the current operations. The risks occasioned by piracy and armed robbery against vessels as identified above are stochastic occurrences with fatal, injury, kidnap for ransom, assault, missing, hostage taking, and death threats forming major risks types identified by IMB assumed to be mutually exclusive and disjoint events. Probability theory asserts that:

P (successful outcome) = number of successful outcomes / Number of possible outcomes

This is the same for the probability of unsuccessful outcome.

Thus the sample space for risks induced by a single pirate attack is represented by the set formed by the sample points as:

$$S = \{Fd, Fi, Fk, Fa, Fm, Fh, Ft\} \quad (3)$$

The probability theory views an event as a subset of the sample space S.

Using the equally likely, fair chance or theoretical probability measure based on the above, we assign the same (fair) probability (P) = 1/N to each pirate attack risk type or outcome types of death, injury, kidnapping, assault, missing, hostage taking and threats to life.

Thus the equally likely probability (expected/theoretical probability) for each outcome type is: 1/7; i.e., 1/7 of the total seafarers exposed to attacks.

The theoretical probability measure assume fair chances for all risk types = 1/7 (N) (4)

The frequency function F(X) of a data set X = X1, X2, X3,…,Xn generates an empirical probability measure F′(X) defined by the equation:

$$F'(X) = \frac{F(X)}{N} \quad (5)$$

The Empirical probability function measure for each piracy risk type (outcomes of pirate attacks) of death, injury, kidnap for ransom, assault, missing of crew, hostage taking, and threats to life was computed using 13 years (2006 -2018) time series observed frequencies of occurrences of each risk type and employing equation (5) such that: Empirical probability coefficient for risks of pirate attacks are:

$$\text{For risk of Death} = F'(Fd) = \frac{F(Fd)}{N} \quad (6)$$

$$\text{Risk of injury} = F'(Fi) = \frac{F(Fi)}{N} \quad (7)$$

$$\text{Kidnap for ransom risk} = F'(Fk) = \frac{F(Fk)}{N} \quad (8)$$

$$\text{Missing crew risk } F'(Fm) = \frac{F(Fm)}{N} \quad (9)$$

$$\text{Risk of assault} = F'(Fa) = \frac{F(Fa)}{N} \quad (10)$$

$$\text{Risk of threats to life} = F'(Ft) = \frac{F(Ft)}{N} \quad (11)$$

$$\text{Risk of hostage} = F'(Fh) = \frac{F(Fh)}{N} \quad (12)$$

Where:

N = aggregate and or average number of crew/seafarers exposed to attacks per period (per annum)

Fd, = frequency of death

Fi = frequency of injury risk

Fk, = frequency of kidnap for ransom

Fa, = frequency of assault

Fm, frequency of crew missing

Fh, frequency of being held hostage

Ft= frequency of death threats

The empirical probability coefficients have a relationship with the per capital output losses due to risks of death, injury, kidnap, etc. For example, given the numbers of crew/seafarers exposed to pirate attacks (N) in any given sea area or economy for any given period and/or year; the product of the empirical probability coefficient of risk of death F' (Fd)and the number of exposure (N) and output per capital/per death gives the total output lost by the economy occasioned by risk of piracy induced deaths over the period. Mathematically put we write that:

$$P_T = F'(Fd)(N)P_N)$$

$$P_T = \frac{F(Fd)}{N} Y \left[\frac{1}{i}\right]\left[1 - \frac{1}{(1+i)^t}(N)\right] \quad (13)$$

N = number of seafarers/crew exposed to pirate attacks

PT = magnitude of probable aggregate output lost due to risks of death in the economy.

Similarly, the output losses as a result of injury, kidnap, etc. can be determined but the period of injury hospitalization and kidnap took 1 year.

5. Limitations of the Study

It is important to state that the data used from the study were sourced from the Nigeria Industrial Trawler Owners Association (NITOA) and the International Maritime Bureau (IMB) piracy reports. Some pirate attacks in the industry may go unreported according general public opinion. There accuracy of these estimations and findings of the study therefore depends to a large extent on the accuracy of the data used.

6. Results and Discussion of Findings

The result shows the average output lost per fishing crew death per annum (human capital death) occasioned by pirate attacks between 2007 and 2013 is $22187.60 between 2007 and 2013. The aggregate output lost by the economy due to death of about 60 fishing crew members between 2007 and 2013 is $1,275,257.505, representing an average annual total output loss of $182, 179.64 per year. The result above represents the indirect output losses to pirate attacks due to deaths alone in the industrial fishery subsector of Nigeria. Similar levels of losses are possibly recorded due to risk of injuries, kidnapping for ransom, etc., which leaves the victims traumatized and unable to work for the periods of hospitalization and treatment. The output losses given above in addition to the direct revenue losses by the NITOA members between 2007 and 2013 indicates a monumental loss and a justification for immediate action of investment in human capital development and funding of youth entrepreneurial schemes and the developmental projects in the coastal communities of the Niger delta, to alleviate the scourge of poverty among the youthful population for enduring solution to the violence of piracy and sea robbery in the Gulf of Guinea maritime domain. See the Table 8 for the financial losses (including decline in productivity, ransom paid for kidnap victims, material and revenue stolen by pirates etc.) by members of NITOA occasioned by piracy and armed robbery attacks against fishing vessel Nigeria.

NITOA report (2015) indicates that the trawler fishery sector lost an aggregate of ₦20,400,000,000 ($56,666,666.67) revenue to pirate attacks between 2007 and 2013 indicating average direct financial losses of ₦3,342,857,142.86 ($9,285,714.29) per annum over the period. By implication, a cumulative of ₦23,859,092,701.62 ($66275257.52) was lost to pirate attacks as direct revenue losses and output losses due to death of fishing crew members in the sub-sector. Piracy and armed robbery attacks against the trawler fishery sector in Nigeria alone induces an annual cost of ₦3,408,441,814.5 ($9,467,893.92) as cumulative cost (direct financial losses and cost of lost output due death of human capital) per annum. These amounts justify any investment in human capital in the Niger delta coastal

Table 7: *Output Losses Due to the Risk of Fatal Attacks in the Industrial Trawler Fisheries Sector in Nigeria*

Year	Deaths	PN = Output per death ($)	PT = Total output losses caused by deaths($)
2007	6	17648.0323	105888.1938
2008	9	21015.7087	189141.3783
2009	13	17721.8126	230383.5638
2010	15	21480.2115	322203.1725
2011	8	23616.1864	188929.4912
2012	6	25739.3131	154435.8786
2013	3	28091.9421	84275.8263
Aggregate		155,313.207	1,275,257.5045
Average		22187.6010	182,179.6435

Source: *Authors calculation based on NITOA data.*

Table 8: *Comparing the Direct Revenue Losses by NITOA and Output Losses Occasioned by Death of Fishing Crew in Naira*

Year	Direct Revenue Losses in Fishing sector (₦)	PT = Total output losses caused by deaths(₦)
2007	2900000000	38,119,749.77
2008	3000000000	68090896.188
2009	3200000000	82,938,082.96
2010	3300000000	115,993.142.1
2011	3000000000	68.014.616.83
2012	3500000000	55596916.296
2013	4500000000	30339297.468
aggregate	23,400,000,000	459,092,701.62
Average	3,342,857,142.86	65,584,671.66

Source: *NITOA. PT = Authors computation based on table10 in Naira. *Note: Exchange rate @360 naira = 1USD.*

communities needed to break the bond of poverty and hopelessness in the coastal communities in a bid to suppress the act of violence and piracy in the Atlantic coast of West Africa at the long run. The likelihood and magnitude of the piracy induced output losses due to death can be forecasted by using the empirical probability coefficient as shown in the Table 9.

The empirical probability coefficient measures the likelihood of actual risk of death occasioned by pirate attacks as against the theoretical/expected probability which assign equal chances of occurrence to all piracy risk types and therefore cannot provide the right information for deployment of strategies against the occurrence of each risk type and the associated economic implications. The result of the analysis shows that the empirical probability of risk of death occasioned by pirate attacks in the trawler fishery sub-sector of Nigeria is 0,007 with average exposure of one-thousand two-hundred and thirty-two crew members (1232) to pirate attacks in the GOG per annum. The implication is that 0.73% of all Nigeria and expatriate crew exposed to pirate attack in the waters of West Africa are killed each year by pirates. Another importance of the empirical probability measure is that if the trend of death by piracy continues, the product of the relationship between the empirical probability coefficient, the number of seafarers (fishing crew) exposed to attacks and the per capital output for the years gives the estimate of the quantum of total output losses per annum due to death of human capital per induced by piracy for that year. See equation 12.

Table 9: *Average Empirical Probability Coefficient of Risk of Death of Fishing Crew by Pirate Attack in Nigeria 2007-2013.*

Risk type	Empirical probability Coefficient	Average death per annum	Average exposure per annum	%
Death	0.007	9	1232	0.73

Source: *Authors calculation based on NITOA data.*

It is important to restate that piracy and armed robbery attacks in the maritime industry affects the global economy since shipping and maritime transport is a global commodity of trade and/or service industry. In Nigeria for example most multinationals operating in the offshore energy sector are foreign owned. Though the financial toll put by piracy in GOG by these organizations remain unreported apart from the often reported attack incidence and kidnaps. It should be the primary responsibility of both the Nigerian authorities, the multinational offshore energy companies in Niger Delta coastal communities and the global maritime industry to make necessary investments in human capital development, youth employment and entrepreneurial development programmes to provide lasting solution to violence and piracy in the GOG. The need for the involvement of the global maritime industry necessitated the estimation of the quantum of output losses occasioned by piracy induced human capital deaths, and injuries in the global maritime industry using IMB piracy statistics and Nigerian per capital output data 2006– 2018.

The total global output losses (using Nigeria per capital output data and IMB data) by the shipping industry as a result of human capital deaths and injuries occasioned by pirate attacks between 2006 and 2018 are 1,474,447.48USD, and 681,735.6247USD, respectively. This implies that the industry lost average output per annum of 134,040.6800USD and 52,441.2019USD, respectively to deaths and injuries to shipping industry human capital. The above losses are exclusive of direct material and revenue losses, and cost of militarizing the waters ways as

Table 10: *Determining the Output Losses Due to Sea Piracy Induced Death and Injury Risks in Ocean Economy using Output Per Capital in Nigeria 2006 - 2018*

Year	Annual Deaths	No. Injured	PN = Output per death ($)	PT = Total output losses caused by deaths($)	PNi=Output losses per injury ($)	PTi = Total output losses caused injury risk ($)
2006	15	15	15,520.70	232810.5	1507.34	22610.1
2007	5	35	17648.0323	88240.1615	1713.9497	59988.2395
2008	11	32	21015.7087	231172.7957	2041.0133	65312.4256
2009	10	69	17721.8126	177218.126	1721.1152	118756.9488
2010	8	37	21480.2115	171841.69	2086.1250	77186.625
2011	8	42	23616.1864	188929.4912	2293.5677	96329.8434
2012	6	28	25739.3131	154435.8786	2499.7625	69993.35
2013	1	21	28091.9421	28091.9421	2728.2462	57293.1702
2014	4	13	30196.6380	120786.552	2932.6511	38124.4643
2015	1	14	25584.1319	25584.1319	2484.6916	34785.6824
2016	-	8	20389.1171	-	1980.1597	15841.2768
2017	3	6	18445.4035	55336.2105	1791.3892	10748.3352
2018	-	8	19004.0644	-	1845.6455	14765.164
Sum			284,453.2613	1,474,447.48	27625.6565	681735.6247
average			21881.0201	134040.6800	2125.0505	52441.2019

Sourced *Authors calculation based on IMB data. *Note: injury estimates are based on hospitalization period of 1 year.*

temporary piracy suppression strategies as earlier identified in literature. Given the propositions of FAT, the magnitude of the losses induced by piracy on the global maritime industry and economy is a sufficient justification to catalyze actions for putting to a lasting end the violence of piracy in the GOG by investment in human capital development programmes, employment and youth entrepreneurial development. This is important, giving the interest of the global community in the region as a major hub of global energy supply. Further estimates of the global shipping industry output losses due to piracy induced death and injury risks in any economy can be determined using the per capital income of the economy, the empirical probability coefficient of each risk type and the number of maritime workers exposed to attacks. See the table below.

The result shows that given the trend of reported piracy and armed robbery attacks against the global maritime industry as reported by International Maritime Bureau (IMB) between 2006 and 2018; empirical probability coefficient of each piracy induced risk type aggregated over the period is 0.001, 0.043, 0.085, 0.0047, 0.0089, 0.82 and 0.022 respectively for death, injury, kidnapping for ransom, missing of crew, assault, hostage taking and threats to life. The global average exposure over the same period is 585.3 maritime workers per annum. The results show that each year, about 1% of all maritime workers who experienced and/or are exposed to attacks by pirates are killed annually; 4.3%, are injured while 8.5% are kidnapped for ransom, 0.47% got missing while 0.89% are assaulted. About 82% are taken hostage until the pirates are able to perform their activities onboard while 2.2% suffer death threats. As stated earlier, the empirical probability coefficients of each risk type when multiplied with the number of maritime workers exposed to pirate attack and the per capital output of the economy yields the estimated output losses in the economy based on the gross output model (note that for injury and kidnap, the period of hospitalization and absence from work need to be specified). See equation 12. It is important to note that hostage taking has the highest likelihood of occurrence with empirical probability coefficient of 0.82 followed by the risk of kidnapping for ransom with empirical probability of 0.085. See Figure 5 below for an arrangement of the pirate attack induced risk types in order to decrease empirical probability and likelihood of occurrence.

7. Conclusion

Evidences from the findings of the study indicate that the Nigeria industrial

Table 11: *Aggregated Empirical Probability Coefficients of Global Risks of Maritime Piracy (2006 -2013)*

Risk type	Empirical probability Coefficient	Average death per annum	Average exposure per annum	%
F' (Fd)	0.01	7	585.3	1%
F' (Fi)	0.043	26	585.3	4.3
F' (Fk)	0.085	51	585.3	8.5
F' (Fm)	0.0047	6	585.3	0.47
F' (Fa)	0.0089	8	585.3	0.89
F' (Fh)	0.82	491	585.3	82
F' (Ft)	0.022	13	585.3	2.2

Source: *Authors' calculation based on IMB statistics.*

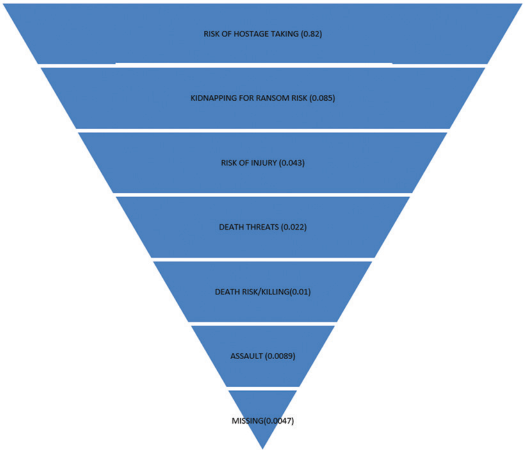

Figure 5: *Empirical Probability of Pirate Attack Induced Risk Types Arranged in Decreasing the Order of Likelihood*
Source: *Authors based empirical probability coefficient of piracy risks result.*

trawler fishery sector lost about 1,275,257.5045USD (₦459, 092,701.62) due to the death of human capital occasioned by pirate attacks in addition to 65,000,000USD (₦23, 400,000,000) direct financial losses between 2007 and 2013. The empirical probability of risk of death by pirate attack in the Nigeria ocean trawler fishery sector is 0.073, implying that about 0.73% of all fishing crew exposed to pirate attacks in Nigeria are killed annually. The global maritime industry is not left out as the global industry suffered output losses of 1,474,447.48USD and 681736.625USD, respectively to deaths and injury risk suffered by maritime workers between 2006 and 2018. This excludes direct financial losses, cost of security, security equipment and training, ransoms paid for release of kidnapped victims, etc. These findings lay credence to public opinion in Nigeria that any investment by the government and the multinational oil and gas corporations in the coastal oil bearing communities of the Niger delta in a bid to put to death the scourge of maritime piracy in the industry is economically justified. It is the opinion of this study that if a minor percentage of amount being wasted by the Government as security budget in militarization the Niger Delta coastal communities annually in the bid to curb violence and pirate activities is dutifully spent in environmental and human capital development programmes cum creation of employment and youth entrepreneurial development and empowerment programmes annually in the coastal communities; the issue of piracy and armed robbery against maritime operators in the GOG will die a perpetual death.

8. Recommendation

Given that piracy and armed robbery attacks cost the Nigerian fishery industry cumulative output losses of 9, 467,893.92USD per year as revealed in the study; in relation to the Nigerian national minimum wage level of 83.3USD (₦30, 000) per month; the economic justification for investment and human capital development in the coastal communities can be based upon these values. By implication, with 9,467,893.92USD, the Government will successfully employ each year in relevant agencies of Government about 9,472 youths from the coastal communities at a monthly wage rate equivalent to the national minimum wage level. The study thus recommend that the trend of frustration induced youth violence, aggression and piracy in the coastal communities in Nigeria and in the entire GOG should be addressed by implementation long term solution strategies that involve using a minor percentage of estimated piracy induced annual losses as a basis for investment in coastal community infrastructures and development programmes. The government and private sector stakeholders in the industry should strike an alliance to ensure the development of the coastal communities to enshrine peace in the waters of the Gulf of Guinea and Nigeria.

9. Suggestions for Further Studies

It is important that further studies be carried to forecast and determine the quantum of years (period of time) needed to crash the level of youth unemployment in the Niger delta coastal communities of Nigeria to the barest minimum by creating 9,472 jobs each year at monthly wage rate equivalent to the national minimum wage rate based on the estimated output losses of 9,467,893.92USD per annum due to piracy and sea robbery attacks. This will provide empirical data to enable stakeholders to plan a long term solution to the challenges of maritime piracy and sea robbery in the West African Coast.

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