IMPLEMENTATION OF STATISTICS IN CONTAINER SHIP SAFETY INSPECTION

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SUMMARY

The IMO developed the Formal Safety Assessment (FSA), which is a systematic and formalized risk assessment methodology that supports decision-making within the IMO. The main objective of the FSA is to provide detailed information on a ship's current level of safety and highlight the need for any necessary changes. In the European Union, a comprehensive FSA was conducted primarily for container ships under a project named SAFEDOR [2], which took place from 2005 to 2009. The project's results were submitted to IMO through MSC83/INF.8, utilizing data on container ship fleets and casualties from 1993 to 2004 for the investigation.

During the COVID period, there has been a significant increase in demand for container ships. In 2020, the global container fleet capacity expanded by almost 3%, reaching 281,784,000 deadweight tons (dwt), while container trade experienced a contraction of 1.1%, totaling 149 million twenty-foot equivalent units (TEU) according to UNCTAD [13].

This study aims to enhance and evaluate the safety performance of all container ships by primarily focusing on integrating the IMO-introduced FSA into vessel inspections. This integration will enable the measurement of all container ships globally using the same scale.

1. INTRODUCTION

To facilitate decision-making through FSA, which involves risk identification, risk mitigation measures, and cost benefits, the IMO initially adopted FSA rules in 2002 via MSC/Circ. 1023 [6]. FSA is a straightforward four-step process, starting with preparation followed by three analysis steps. In step two, a quantitative risk evaluation is conducted to assess the current level of safety on board specific container ships. This step emphasizes the need for implementing mitigating measures. Risk levels are categorized into three tiers to acknowledge the need for improvement and mitigation:

- High risk: Indicates extremely high risk levels that must be promptly addressed at any cost.
- Medium risk: Risk should be efficiently managed as soon as practically possible.
- Low risk: No further improvement is needed, but the existing level should be maintained.

Since their inception in 1997 for high-speed spacecraft, FSAs have been utilized across various vessel classes. Over the years, FSAs have been conducted for bulk carriers, LNG ships, crude oil tankers, RO-Ros, cruise ships, and containerships. Initially, these FSAs were examined by experts selected by IMO member states and then submitted to the appropriate IMO committee for further evaluation.

The subsequent sections will provide a detailed description of how these risk levels are determined for containerships for the purpose of this study.

2. INDUSTRY CHALLENGES

According to Statista [12], the global shipment of cargo is projected to reach 1.85 billion metric tonnes, a significant increase from 0.1 billion metric tonnes in 1980. Correspondingly, the size of the world's container fleet has also grown. It has expanded from 11 million metric tonnes in 1980 to approximately 275 million metric tonnes in 2020 (last updated data), reflecting the increased deadweight tonnage of container ships. It is crucial to recognize that container fleets play a fundamental role in transporting consumer goods. Therefore, ensuring the prompt and safe delivery of orders is of utmost importance.

Furthermore, it is noteworthy that 68.3% of severe ship-related casualties occurred on container ships, general cargo ships, and bulk carrier vessels between 2014 and 2020, as reported by EMSA [3]. Container vessels contributed to 17.5% of these incidents. Vessel inspection serves as one of the most critical steps in assessing the safety condition of a ship. This study aims to make the process of vessel inspections quantifiable and meaningful, providing an opportunity to identify the true areas of risk.

3. LITERATURE REVIEW

Over the past few decades, significant progress has been made in maritime safety, particularly in risk quantification analysis. Various efforts have been made to improve safety standards in the shipping industry. Yang et al [15] explored the challenges in conducting marine safety analysis and the various methods for estimating hazards associated with maritime transportation. The study also highlights the limitations of FSAs and discusses the latest advancements by the International Maritime Organization (IMO).

A key focus of Yang et al [15] paper is to highlight the shortcomings of FSA. However, FSA itself offers substantial scope and quantitative analytical techniques that can contribute to assigning risk weights to individual vessels globally.

In another study by Hänninen, M. et al [5], a model for managing marine safety and related subfields is presented. The study establishes a connection between safety management and marine traffic safety, as demonstrated by accident involvement, events recorded by the Vessel Traffic Service, and findings from Port State Control inspections. Based on this study, the authors attempt to link all areas of ISM (International Safety Management) and, in turn, the vessel SMS (Safety Management System).

With the recent introduction of SIRE 2.0 in the fourth quarter of 2022, which applies to tanker vessels, the need for quantitative analysis has become increasingly important. In a recent study by Linardou, V. [7], the emphasis on SIRE 2.0 and the requirement for quantitative analysis for tanker vessels are explained, aligning with the SIRE 2.0 requirements.

Another study by Wang, J. et al [14] provides descriptions of container ships and discusses the evolution of formal safety assessment in the shipping sector. The study examines and analyzes statistics on container ship incidents. It also outlines the characteristics of container ships and provides a systematic safety evaluation methodology for them. Finally, the study thoroughly discusses future developments in formal safety assessment concerning container ship safety.

The study by Raptodimos, Y. et al [11], presents an onboard measurement campaign for a container ship case study and offers an approach for monitoring critical mechanical systems. The paper explains how to collect significant machinery data and parameters from critical systems located in the ship's engine room, including the selection of systems to be monitored, monitoring scenarios, sensors, portable equipment, and the physical parameters to be checked. However, this study by Raptodimos, Y. et al [11] is limited to the collection of data on critical machinery. While it holds significant importance, it does not provide an accurate assessment of the overall vessel condition but rather focuses on individual machinery conditions.

Considering multiple studies conducted in the field of maritime safety, questions are raised regarding data collection techniques at various stages. To address these challenges, this study not only addresses data collection techniques but also offers a comprehensive overview of the risk status of individual vessels and identifies specific areas that require immediate attention to mitigate potential losses.

4. RESEARCH DESIGN AND SCOPE

4.1 DEFINITION AND METHODOLOGY OF FMEA

Efficient risk analysis in the context of FSA (Formal Safety Assessment) would greatly benefit from a clear statement of the technique used and a logical classification of risk elements. In this section, the methods and techniques for an efficient FSA are discussed in detail.

One design and engineering tool that aids in investigating potential failure modes within a system and assessing their impact is called FMEA (Failure Mode Effective Analysis) [4]. Over time, businesses have utilized the FMEA technique to reduce failures and minimize the potential negative consequences on safety, the environment, and the economy.

FMEAs have recently gained popularity as a risk analysis approach in the marine industry [4]. It is mandated by the International Maritime Organization, Classification Societies, certain regulatory agencies, and industry associations for specific systems to enhance safety, reliability, and the system's ability to prevent unintended incidents. FMEAs are considered a vital component of the design process for many forward-thinking businesses as part of their risk management strategy.

The construction of an FMEA involves a tabletop analytical technique that identifies design and configuration issues within the system across all anticipated operational modes [4].

During FMEA, all possible failure modes, their impacts, detection techniques, and remedial measures are listed. However, the focus is not solely on corrective actions in such situations; instead, FMEA is used to identify risks and logically assign weightages to them.

FMEAs provide a systematic approach to identifying hazardous situations, addressing gaps and connection variations, and enhancing safety, environmental performance, and operational efficiency. By identifying the riskiest factors, mitigation efforts can be prioritized on the risks that carry the highest significance.

In this study, an improved method for distributing final scores for each check (which may be conducted during a vessel inspection) has been developed, aiming to enhance its effectiveness. The scoring method assigns a higher weight to checks that carry the highest risk. This approach ensures that the distribution of scores within the survey parts is reasonable, leading to meaningful and valuable results. It also serves as a cohesive strategy, allowing for the efficient selection and focus on the most crucial aspects/ areas that require immediate attention onboard ships.

FMEAs offer several benefits, including:

- Identification of critical areas: FMEAs help pinpoint areas that pose significant risks, allowing for targeted risk mitigation efforts.
- Streamlined implementation of safety precautions: By ensuring uniformity in the breadth, depth, and quality of all assessments, FMEAs facilitate the process of implementing safety measures.
- Reduction in incidents, downtimes, and failures: Through the identification and mitigation of potential failure modes, FMEAs contribute to minimizing incidents, operational downtimes, and failures, thereby improving overall safety and reliability.

4.1 (a) Purpose of FMEA

In situations where system failure can have unintended consequences such as loss of propulsion or loss of propulsion control, it is considered a best practice to conduct a risk analysis, such as an FMEA, during the design and operational processes. Risk assessments such as FMEAs provide a systematic approach to identifying potentially hazardous situations, addressing gaps and connectivity issues, and improving safety, environmental performance, and operational efficiency. Once the most critical checks have been identified, the distribution of final grades to each check becomes a more streamlined process.

FMEAs help in identifying critical areas and significant regions that require attention. They contribute to reducing failures, downtimes, and incidents by ensuring consistency in the scope, depth, and quality of assessments. FMEAs also accelerate the implementation of protective measures for potentially hazardous situations.

In this study, a three-layer risk detection method incorporating severity, occurrence, and detection (referred to as SOD) will be employed, along with the concept of detectability. The Risk Priority Number (RPN) encompasses all three factors. Figure 1 illustrates a simplified three-step FMEA process. [8]

A similar approach was utilized for container terminals [9]. This study will adopt a similar model for the safety inspection of container ships.

4.1 (b) Likert Scale

The risk assessment process in this study incorporates three factors: severity, occurrence, and detection. These factors are used to rate the potential risks associated with failures.

- Severity: This factor rates the seriousness of the potential effect that a failure can have. The severity ratings are performed on a scale of 1 to 5, where 1 represents an extremely low severity of the risk and 5 represents an extremely high severity of the risk.
- Occurrence: This factor rates the likelihood or probability that a failure will occur. Similarly, ratings are done on a scale of 1 to 5, where 1 indicates that the failure is very unlikely to occur and 5 indicates that the failure is very likely to occur.
- Detection: This factor rates the likelihood that the problem or failure will be detected before this leads to a larger failure or incident. Ratings are also performed on a scale of 1 to 5, with 1 indicating a high likelihood of detection and 5 indicating a low likelihood of detection.

These rating scales help in quantifying and assessing the risks associated with different failure modes. They provide a standardized way to evaluate and prioritize risks based on their severity, occurrence probability, and detectability. See Table 1.

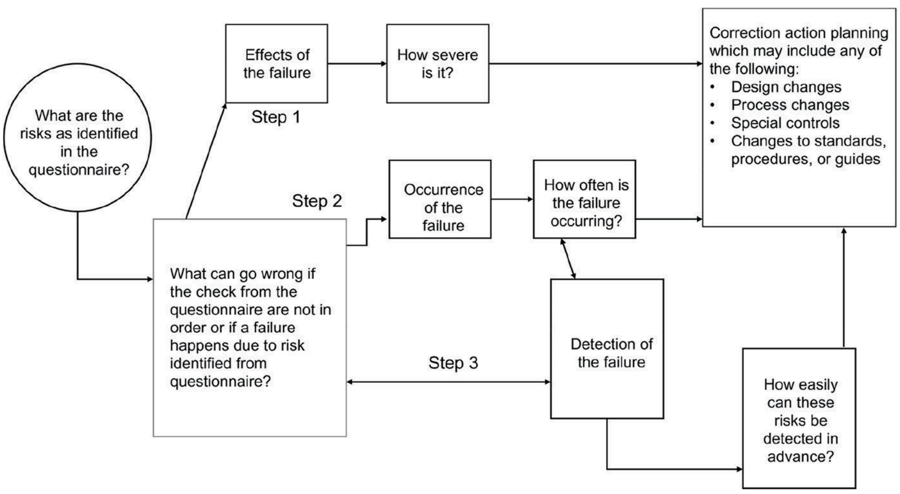

Figure 1. The 3 Steps of FMEA process

Table 1. Ratings on Likert Scale

Rating	Severity	Occurrence	Detection
1	Very low or negligible	Very or negligible probability	Very Easily detected
2	Low or minor	Low or minor probability	Slightly difficult to detect
3	Moderate or significant	Moderate or significant probability	Significantly easy to detect
4	High	High probability	Difficult to detect
5	Very high catastrophic	Extremely high probability	Extremely difficult to detect

5. SURVEY AND RESULTS

For this study, a survey was conducted among maritime professionals from ABC shipping company (Company name hidden due to confidentiality) and external maritime professionals. The survey aimed to gather responses on various aspects related to safety and schedule reliability.

The questionnaire was structured into four main sections, allowing respondents to record their responses in each section. The sections included the following:

- Safety of the Crew (SOC): This section focused on assessing safety measures and concerns related to crew members working on vessels. Respondents were asked to provide their feedback and insights on crew training, emergency preparedness, safety culture, and any specific crew-related risks on a Likert scale of 1 to 5.
- Safety of the Vessel (SOV): This section aimed to evaluate the safety aspects related to the vessel itself. Respondents were asked to mark on a Likert scale of 1 to 5 and share in their opinion how critical is the maintenance of the vessel, adherence to safety regulations, equipment reliability, and any vessel-specific risks or concerns.
- Safety of the Cargo (SOCR): This section addressed the safety considerations regarding the containers being transported. Respondents were again asked to mark on a Likert scale of 1 to 5 to provide their views on the importance of cargo handling procedures, stowage and securing practices, compliance with safety guidelines, or any cargo-related risks or challenges.
- Schedule Reliability (SR): This section focused on assessing the reliability of the vessel's schedule and timeliness of deliveries. Respondents were asked to rate their experiences and observations on a Likert scale of 1 to 5 regarding on-time performance, schedule disruptions, and any factors affecting the vessel's schedule reliability.

Table 2 provides an overview of the different sections of the questionnaire and their respective nomenclature.

Table 2. Section Nomenclature

Section	Nomenclature
Section 1 (Safety of the Crew (SOC))	1.0
Section 2 (Safety of the Vessel (SOV))	2.0
Section 2 (Safety of the Cargo (SOCR))	3.0
Section 2 (Schedule Reliability (SR))	4.0

The survey received responses from a total of 14 maritime professionals. The respondents were categorized based on their departments within the ABC shipping company. The distribution of respondents among different departments is as follows:

- Technical management and marine standards: 35.7%
- Fleet technology: 7.1%
- Other departments: 21.4%

The combined experience of all the respondents is approximately 270 years. The majority of the respondents, accounting for 85.7%, have over 20 years of experience. Additionally, 14.3% had ranging from 16 to 20 years of experience. Table 3 provides an overview of the distribution of respondents based on their departments and the years of experience they possess.

6. METHODOLOGY

In this study, a 95% confidence interval is calculated using secondary data obtained from ABC shipping limited. The confidence interval provides a range of values within which it can be said that 95% of the true population parameter lies.

For the calculation of risks and thresholds, the entire population is considered. This means that all available data from ABC shipping limited is used to determine the risks and set the appropriate thresholds.

For the data collected from the survey/questionnaire, as described in Section 5, mode and median calculations are used to determine the severity, occurrence, and detection. The mode represents the most frequently occurring value, while the median represents the middle value when the data are arranged in ascending or descending order. These calculations help in assessing the central

Table 3. Respondents Profile

Maritime Professional	Current Department	Current position	Years of experience
Yes	Marine standards	Director	more than 20
Yes	Technical Management	Senior tech supdt	more than 20
Yes	Fleet technology	People, environment, cargo	more than 20
Yes	Other:	Senior Marine Manager	more than 20
Yes	Marine standards	Project Manager -LNG Transition	more than 20
Yes	Technical Management	Assistant Fleet manager	more than 20
Yes	Marine standards	Co-Founder of risk management company	more than 20
Yes	Other:	Manager	16–20
Yes	Other:	Director, Business Transformation	more than 20
Yes	Technical Management	Project Manager	16–20
Yes	Technical Management	Superintendent	more than 20
Yes	Marine standards	QHSE suptd	more than 20
Yes	Technical Management	VP, Asset Integrity	more than 20
Yes	Marine standards	Master Mariner	more than 20

tendency of the data and understanding the distribution of responses.

6.1 NORMAL DISTRIBUTION

For this study, since the data sets are large it is assumed that the data are normally distributed. The concept of normal distribution, also known as a Gaussian distribution, is a mathematical model that describes a symmetric bell-shaped curve. It is characterized by its mean (average) and standard deviation. In a normal distribution, the majority of data points cluster around the mean, with progressively fewer data points further away from the mean.

The central limit theorem is a fundamental statistical principle that helps explain why large data sets tend to approximate a normal distribution. It states that the sum (or average) of a large number of independent and identically distributed random variables will have an approximately normal distribution, regardless of the underlying distribution of the individual variables. This means that even if the data in a large data set do not follow a normal distribution, the distribution of the sample means or sums will tend to resemble a normal distribution.

Therefore, for this study, the assumption of normality is made due to the central limit theorem. Considering that data is normally distributed with large population size or even with samples [1], in this study, the 95% confidence interval (1) is used to assess the inspection scores (Calculation is described in subsequent sections of this study) and determine if they fall within a certain range. See Figure 2. Secondary data are used to plot Figure 2 where all data points (Column 2 of Table 7, Total score) falling below 57.137 are shaded Red and above 64.695 are shaded Green and in-between is Yellow.

Data points that fall outside the range of the 95% confidence interval are considered outliers. These outliers indicate that the inspection scores deviate significantly from the expected range and may require closer examination. If outliers are identified, it is important to investigate the reasons behind these deviations and take necessary corrective actions to address any potential issues or risks.

$$\mu \pm 1.96\left(\frac{\sigma}{\sqrt{N}}\right) \tag{1}$$

where:
μ is the population mean,
1.96 is the z score for a 95% confidence level,
σ is the population standard deviation,
N is the population size.

Equation 1 represents the 95% confidence interval formula. The mean represents the average of the inspection scores, and the standard deviation measures the variability or spread of the scores around the mean. By applying this formula, the upper limit and lower limit of the threshold can be calculated for inspection scores. Inspection scores falling outside this range would be considered outliers and would require further investigation and corrective action as deemed necessary.

6.2 ASSIGNING TOTAL SECTION SCORES

The total value of the survey inspection is assigned a fixed value of 100. Based on survey results where respondents

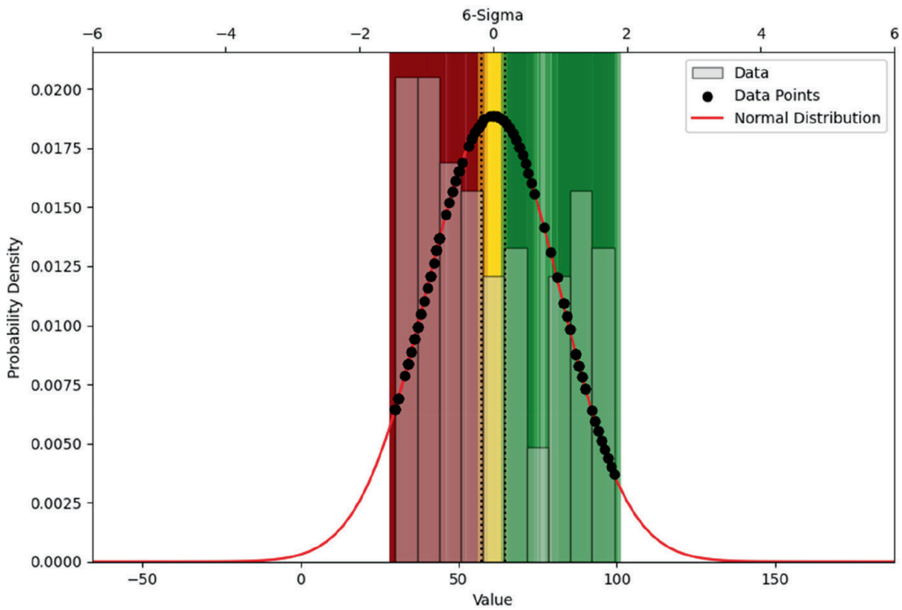

Figure 2. The standard Normal distribution curve with secondary data (Data = Total Score (Column 2, Table 7))

were asked "For a container ship, which factor do you consider as the most important from a safety perspective?" 78.6% of respondents consider the safety of the crew to be the most prudent factor towards any inspection or survey. Based on this, the safety of the crew section will have the highest weightage out of 100, which is a 30.

Table 4 shows the score distribution out of 100 towards the respective section as laid out in the questionnaire.

Table 4. Weightage and Total RPN Value

Section	Weightage	Total RPN Value
Safety of the crew (SOC)	30	492
Safety of the vessel (SOV)	25	301
Safety of the cargo (SOCR)	25	241
Schedule reliability (SR)	20	321

6.3 CALCULATING INDIVIDUAL SECTION CHECK/RISK SCORES

To anticipate how an incident may impact safety, as a first step, the RPN score is calculated:

$$RPN = Severity \times Occurrence \times Detection \qquad (2)$$

Equation 2 represents the calculation of the RPN.

To calculate the weightage of each check within a section, the RPN (Risk Priority Number) score and the total RPN score of the section will be used. The weightage of each check can be determined using the following formula:

$$\frac{RPN\ value\ of\ check \times Total\ section\ score}{Total\ RPN\ of\ section} \qquad (3)$$

Equation 3 represents the calculation of the weightage of an individual check/risk.

For example, consider Risk/Check No. 1.1 from the Safety of the Crew section with a weightage of 30 and an RPN score of 60 (calculated using 2). If the sum of all RPN values in the Safety of the Crew section is 530, weight (3) of Risk/Check 1.1 is calculated as follows:

Weightage of Risk 1.1 = (60/530) * 30 = 3.40 (rounded to two decimal places) Therefore, Risk 1.1 will have a weightage of approximately 3.40 within the Safety of the Crew section.

This calculation can be applied to each check within the section to determine their respective weightages based on their RPN scores and the overall RPN score of the section.

If a particular check during an inspection is not complying, the vessel would lose a score equivalent to the weightage of that check. The weightage of each check, as calculated based on the RPN scores and the overall RPN score of the section, represents the importance or significance of that check within the section.

For example, if Check 1.1 in the Safety of the Crew section has a weightage of 3.40 (as calculated in the previous example) and the vessel fails to comply with this check, the vessel would lose a score of 3.40 in the Safety of the Crew section.

This approach allows for a quantifiable assessment of non-compliance, where the severity of non-compliance is reflected in the loss of score proportional to the weightage of the check. By deducting the weightage from the total score, the inspection outcome reflects the impact of non-compliance on the overall assessment of the vessel's safety.

Table 5. Individual risk weighted score

ID	Risk	RPN	RPN Total	Weighted score
Section 1				
Check 1.1	Importance of Gangway condition	30	492	1.83
Check 1.2	Importance of gangway rigging arrangement	30	492	1.83
Check 1.3	Importance of PPE	30	492	1.83
Check 1.4	Importance of handrails or fixed guard rails	10	492	0.61
Check 1.5	Importance of collapsible handrails	60	492	3.66
Check 1.6	Importance of mooring ropes	80	492	4.88
Check 1.7	Importance of lashing bridges/catwalks	45	492	2.74
Check 1.8	Importance of gratings	60	492	3.66
Check 1.9	Importance of oil leaks in Engine room	80	492	4.88
Check 1.10	Importance of illumination in Engine room	15	492	0.91
Check 1.11	Importance of illumination on deck	12	492	0.73
Check 1.12	Importance of ladders in cargo holds	20	492	1.22
Check 1.13	Importance of pilot ladders	20	492	1.22
Section 2				
Check 2.1	Importance of Navigation equipment	15	301	1.25
Check 2.2	Importance of passage planning	40	301	3.32
Check 2.3	Importance of loadicator	40	301	3.32
Check 2.4	Importance of remote tank sounding system	10	301	0.83
Check 2.5	Importance of watertight doors	10	301	0.83
Check 2.6	Importance of lagging in Engine room	15	301	1.25
Check 2.7	Importance of freeboard and draught marks	5	301	0.42
Check 2.8	Importance of emergency generator	15	301	1.25
Check 2.9	Importance of steering gear	20	301	1.66
Check 2.10	Importance of emergency fire pump	15	301	1.25
Check 2.11	Importance of fire detection system	15	301	1.25
Check 2.12	Importance of oily water separator	8	301	0.66
Check 2.13	Importance of sewage treatment plant	6	301	0.50
Check 2.14	Importance of engine room fire dampers	20	301	1.66
Check 2.15	Importance of hydraulic system for deck machinery	12	301	1.0
Check 2.16	Importance of fire detection system in cargo holds	30	301	2.49
Check 2.17	Importance of fixed firefighting system	15	301	1.25
Check 2.18	Importance of portable firefighting system	10	301	0.83

(Continued)

Table 5. Continued

ID	Risk	RPN	RPN Total	Weighted score
Section 3				
Check 3.1	Importance of cargo hold bilge alarms	10	241	1.04
Check 3.2	Importance of cargo hold ventilation trunks	5	241	0.52
Check 3.3	Importance of cargo hold ventilation blowers	15	241	1.56
Check 3.4	Importance of cargo hold cell guides	8	241	0.83
Check 3.5	Importance of cargo hold fixed stacking cones	36	241	3.73
Check 3.6	Importance of container sockets	80	241	8.30
Check 3.7	Importance of lashing eyes	15	241	1.56
Check 3.8	Importance of lashing gear reserve	8	241	0.83
Check 3.9	Importance of lashing gear condition	20	241	2.07
Check 3.10	Importance of electrical container sockets	12	241	1.24
Check 3.11	Importance of hatch covers	8	241	0.83
Check 3.12	Importance of hatch coaming plating including deck connection, stiffeners, stays, pads, chocks, brackets and securing pins	24	241	2.49
Section 4				
Check 4.1	Importance of fuel oil transfer syste m	16	321	1.00
Check 4.2	Importance of sea water system	16	321	1.00
Check 4.3	Importance of overboard valves	20	321	1.25
Check 4.4	Importance of LO cooler	12	321	0.75
Check 4.5	Importance of sea water cooler	16	321	1.00
Check 4.6	Importance of maintenance of Aux engines	8	321	0.50
Check 4.7	Importance of maintenance of Main engine	60	321	3.74
Check 4.8	Importance of main engine turbocharger	24	321	1.50
Check 4.9	Importance of exhaust gas receiver/piping	4	321	0.25
Check 4.10	Importance of stern tube	60	321	3.74
Check 4.11	Importance of boiler	30	321	1.87
Check 4.12	Importance of thrusters	6	321	0.37
Check 4.13	Importance of low insulation (440V/220V)	9	321	0.56
Check 4.14	Importance of planned maintenance system	6	321	0.37
Check 4.15	Importance of windlass	8	321	0.50
Check 4.16	Importance of winches	8	321	0.50
Check 4.17	Importance of steering gear	10	321	0.62
Check 4.18	Importance of Lube oil analysis (Applicable to machineries which can lead to offhire such as Main Engine, Aux. Engine, Steering gear, Winches/windlass, Cargo gear etc.)	8	321	0.50

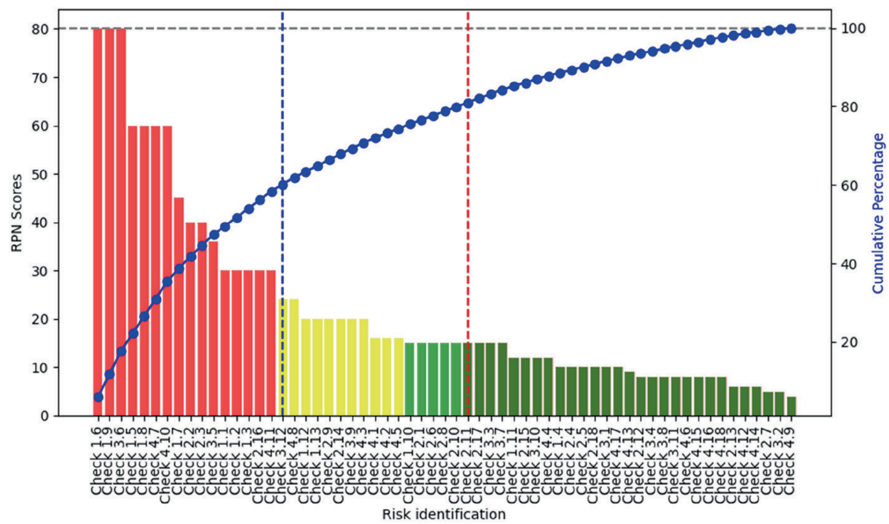

Figure 3. Pareto Analysis

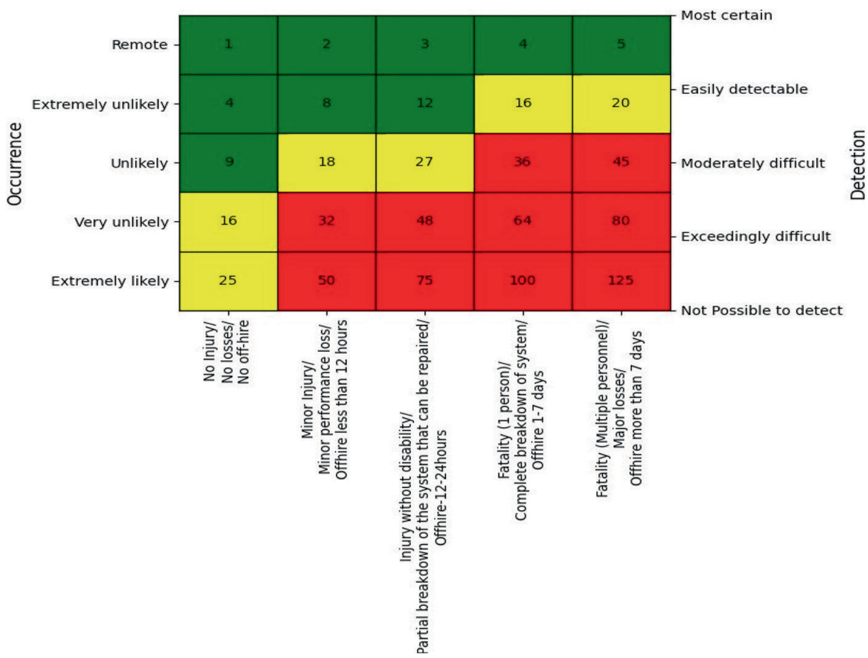

Figure 4. Risk Matrix

6.4 DETERMINING THE FINAL RPN VALUE

In this study, the modes and medians are considered to assign Likert scale values for each risk based on the responses of the respondents. The mode is used when there is a clear majority response, while the median is used when there are no modes or multiple modes.

For example, if 8 out of 10 respondents select a value of 4 for severity and the remaining 2 select 3 and 2, the final assigned severity value will be 4 as it is the mode in this case. Similarly, if the responses for a check are 1, 1, 1, 2, 2, 3, 3, 4, 4, 5, 5, 5, the median value will be 3 since there are multiple modes present.

Averages or means are not considered in this study as the sole purpose of defining the metrics. This is because averages can be misleading and may not provide accurate results. The presence of outliers, which are values that are significantly different from the rest of the data, can heavily influence the mean. By using modes and medians, this study aims to avoid the impact of outliers and provide a more robust assessment of the assigned values.

Table 5 provides the calculated RPN values for each risk, and Table 4 shows the total RPN value per section.

7. DATA ANALYSIS

7.1 PARETO ANALYSIS

After determining the RPN values using the techniques described in section 6.4, a Pareto analysis is performed to statistically identify the most significant risks. This analysis helps differentiate between high-risk factors and low-risk factors. By applying the 80-20 rule, the risks are subdivided into cumulative percentages of 80% and 60%.

Based on the Pareto analysis, the risk bands are calculated as follows:

- Checks with RPN values ranging from 30 to 125 are categorized as high risk.
- Checks with RPN values ranging from 16 to 29 fall into the medium risk category, representing the cumulative range from 80% to 60%.
- Checks with RPN values ranging from 0 to 15 are categorized as low risk.

This categorization helps prioritize the identified risks based on their severity, occurrence, and detection, allowing for more focused attention on the high-risk factors. Figure 3 provides a visual representation of this categorization.

7.2 DESIGNING THE RISK MATRIX

Since the analysis is based on severity, occurrence, and detection, and the Likert scale chosen for this study is on a scale of 1 to 5, the risk matrix would be a 5×5×5 matrix. Each dimension of the matrix represents one of the following factors: Severity, Occurrence, and Detection.

The risk matrix is used to assess the overall risk level based on the combination of severity, occurrence, and detection. The values from the Likert scale are mapped onto the matrix to determine the corresponding risk level.

Using the risk bands defined in Section 7.1 (high risk, medium risk, and low risk), the risk matrix would have different regions or zones corresponding to each risk level. These zones can be represented in the matrix to visually illustrate the level of risk based on the combination of severity, occurrence, and detection.

Figure 4 provides a visual representation of the risk matrix, indicating the different zones or regions corresponding to high risk, medium risk, and low risk based on the defined risk bands.

7.3 ASSIGNING RISK BANDS AND WEIGHTAGES TO INDIVIDUAL CHECKS

Based on the risk matrix, each check within the sections can be assigned to their respective risk bands, indicating whether they fall into the categories of high, medium, or low risk. Additionally, scores can be assigned to each risk within the sections, namely Safety of the Crew (SOC),

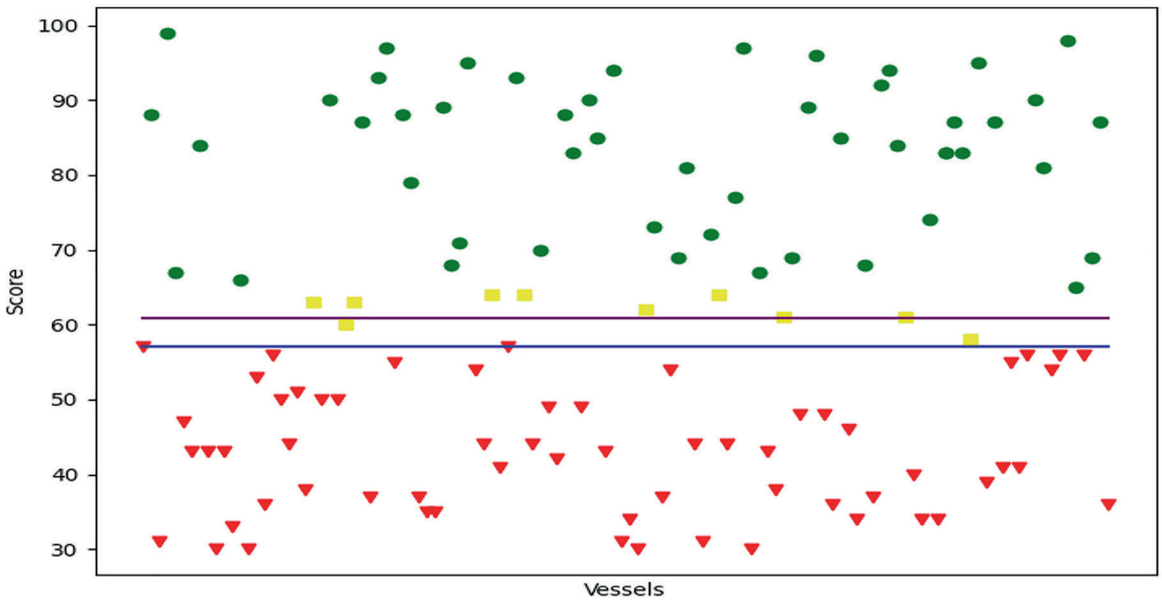

Figure 5. Vessel Overall Risk status

[1] Green circles depict the low risk vessels. In total, there are 49 low risk vessels
[2] Yellow squares depict the medium risk vessels. In total, there are 10 medium risk vessels
[3] Red triangles depict the high risk vessels. In total there are 61 high risk vessels.
[4] Purple upper line indicates the Upper limit i.e., 64.70.
[5] Blue lower line indicates the Lower limit i.e., 57.14.

Risk Category in any of the section	Risk Category in any of the section	Risk Category in any of the section	Risk Category in any of the section	Final Risk
H	H	H	H	H
H	H	H	M	H
H	H	H	L	H
H	H	M	L	H
H	H	L	L	H
H	H	M	M	H
H	L	L	L	M
H	L	L	M	M
H	L	M	M	M
H	M	M	M	H
M	M	M	M	M
M	L	L	L	L
M	M	L	L	M
M	M	M	L	M
M	M	M	M	M
L	L	L	L	L

Figure 6. Final Risk Matrix

[1] H - High risk in Red colour
[2] M - Medium risk in Yellow colour
[3] L - Low risk in Green colour

Safety of the Vessel (SOV), Safety of the Cargo (SOCR), and Schedule Reliability (SR). Refer to Table 5 for more details.

7.4 BENCHMARKING

Secondary data from ABC shipping, which includes information on a total of 120 container vessels, were collected for this study. The existing vessel internal inspection data were categorized into the sections as outlined in this study, as shown in Table 7, Column 2 – Total Score. Weightages and individual scores were assigned to all checks based on the methodology described in the study (see Section 6 and Section 7).

Each vessel is then assigned an individual risk score. Using the 95% confidence interval approach (1), where the average fleet score was 60.92, the standard deviation was 21.12, and the total population was 120 vessels, it is determined that the upper limit is 64.70 and the lower limit is 57.14.

Based on these limits, vessels with a score below 57.14 are classified as high-risk vessels, vessels with a score above 64.70 are classified as low-risk vessels, and vessels with a score between 57.14 and 64.70 are classified as medium-risk vessels. This information is presented in Table 7, where it is shown that there are 49 low-risk vessels, 61 high-risk vessels, and 10 medium-risk vessels.

By benchmarking all vessels and plotting them on a single chart, their risk state can be visually monitored. Figure 5[1,2,3,4,5] illustrates this chart, which allows for a comprehensive view of the risk levels of each vessel.

8. FEASIBILITY ANALYSIS

The study hypothesized that if individual vessels are assigned risks solely based on an algorithm-based approach, then the weightages assigned would accurately reflect the vessel's true condition. However, it is important to note that while the overall score (Table 7, Column 2 – Total score) indicates a vessel's condition, it does not provide a comprehensive understanding of the specific areas where the vessel may be lacking.

For example, a vessel may have a high overall score, but it could be that the vessel is poor in terms of safety of the vessel (SOV), while the safety of the crew (SOC), safety of the cargo (SOCR), and schedule reliability (SR). In such cases, it becomes crucial to identify in which area the vessel is lacking and hence to accurately assign the true risk to the vessel into the specific areas where the problems lie becomes prudent.

Evaluating the safety of container ships requires a comprehensive assessment that focuses on identifying the specific areas of concern. This study aims to address this agenda by analyzing the risks associated with each section individually, allowing for a more nuanced understanding of the vessel's safety conditions.

8.1 DESIGNING THE FINAL RISK MATRIX

With this study, the breakdown of the upper and lower limits for individual sections, such as safety of the crew (SOC), safety of the vessel (SOV), safety of the cargo (SOCR), and schedule reliability (SR), can be performed to obtain a more accurate assessment of the vessel's true condition. It is possible that a vessel may be categorized as

Table 7. Vessel Scores and Risk Categorization

Vessel Name	Total Score	Initial Risk	SOC Score	SOV Score	SOCR Score	SR Score	Final Risk
Vessel 1	57	H	12	9	25	11	H
Vessel 2	88	L	29	25	14	20	M
Vessel 3	31	H	15	6	5	5	H
Vessel 4	99	L	30	25	25	19	L
Vessel 5	67	L	15	11	21	20	H
Vessel 6	47	H	16	8	8	15	M
Vessel 7	43	H	15	11	15	2	H
Vessel 8	84	L	29	24	20	11	M
Vessel 9	43	H	8	10	16	9	H
Vessel 10	30	H	5	10	11	4	H
Vessel 11	43	H	20	10	10	3	H
Vessel 12	33	H	5	5	10	13	H
Vessel 13	66	L	25	15	10	16	H
Vessel 14	30	H	10	10	5	5	H
Vessel 15	53	H	10	10	20	13	H
Vessel 16	36	H	10	10	15	1	H
Vessel 17	56	H	15	15	20	13	H
Vessel 18	50	H	15	25	10	10	H
Vessel 19	44	H	17	10	10	7	H
Vessel 20	51	H	11	17	15	8	H
Vessel 21	38	H	10	10	15	3	H
Vessel 22	63	M	15	18	12	18	H
Vessel 23	50	H	10	20	15	5	H
Vessel 24	90	L	28	22	20	20	L
Vessel 25	50	H	10	20	15	5	H
Vessel 26	60	M	6	12	21	21	H
Vessel 27	63	M	16	12	24	11	H
Vessel 28	87	L	28	22	18	19	L
Vessel 29	37	H	10	10	10	7	H
Vessel 30	93	L	30	20	25	18	L
Vessel 31	97	L	30	25	22	20	L
Vessel 32	55	H	14	13	22	6	H
Vessel 33	88	L	29	25	15	19	L
Vessel 34	79	L	25	14	25	15	M
Vessel 35	37	H	10	10	12	5	H
Vessel 36	35	H	10	10	10	5	H
Vessel 37	35	H	10	8	8	9	H
Vessel 38	89	L	25	22	24	18	L
Vessel 39	68	L	24	11	20	13	M
Vessel 40	71	L	28	24	12	7	H
Vessel 41	95	L	30	24	25	16	L
Vessel 42	54	H	12	12	17	13	H
Vessel 43	44	H	10	15	10	9	H
Vessel 44	64	M	10	15	25	14	H
Vessel 45	41	H	15	10	11	5	H
Vessel 46	57	H	17	14	19	7	H
Vessel 47	93	L	30	25	18	20	L

(Continued)

Table 7. Continued

Vessel Name	Total Score	Initial Risk	SOC Score	SOV Score	SOCR Score	SR Score	Final Risk
Vessel 48	64	M	17	18	20	9	H
Vessel 49	44	H	10	14	14	6	H
Vessel 50	70	L	7	24	23	16	M
Vessel 51	49	H	10	20	12	7	H
Vessel 52	42	H	15	15	10	2	H
Vessel 53	88	L	25	25	23	15	L
Vessel 54	83	L	28	20	16	19	L
Vessel 55	49	H	20	8	7	14	H
Vessel 56	90	L	30	24	16	20	L
Vessel 57	85	L	28	20	17	20	L
Vessel 58	43	H	10	12	10	11	H
Vessel 59	94	H	30	25	20	19	L
Vessel 60	31	H	10	6	8	7	H
Vessel 61	34	H	8	7	10	9	H
Vessel 62	30	H	7	5	7	11	H
Vessel 63	62	M	29	11	13	9	H
Vessel 64	73	L	29	10	15	19	M
Vessel 65	37	H	8	7	12	10	H
Vessel 66	54	H	9	21	21	3	H
Vessel 67	69	L	15	17	17	20	M
Vessel 68	81	L	29	17	17	18	L
Vessel 69	44	H	15	7	8	14	H
Vessel 70	31	H	6	7	8	10	H
Vessel 71	72	L	21	14	17	20	M
Vessel 72	64	M	10	14	23	17	H
Vessel 73	44	H	8	15	13	8	H
Vessel 74	77	L	18	15	24	20	M
Vessel 75	97	L	30	25	23	19	L
Vessel 76	30	H	8	9	10	3	H
Vessel 77	67	L	18	15	14	20	M
Vessel 78	43	H	10	7	14	12	H
Vessel 79	38	H	8	7	9	14	H
Vessel 80	61	M	6	19	25	11	H
Vessel 81	69	L	22	10	24	13	M
Vessel 82	48	H	28	10	8	2	H
Vessel 83	89	L	28	18	24	19	L
Vessel 84	96	L	30	25	23	18	L
Vessel 85	48	H	20	15	8	5	H
Vessel 86	36	H	5	18	7	6	H
Vessel 87	85	L	28	15	24	18	L
Vessel 88	46	H	14	15	8	9	H
Vessel 89	34	H	14	8	8	4	H
Vessel 90	68	L	22	11	17	18	M

(Continued)

Table 7. Continued

Vessel Name	Total Score	Initial Risk	SOC Score	SOV Score	SOCR Score	SR Score	Final Risk
Vessel 91	37	H	10	10	8	9	H
Vessel 92	92	L	28	20	24	20	L
Vessel 93	94	L	29	25	20	20	L
Vessel 94	84	L	30	22	17	15	L
Vessel 95	61	M	20	15	18	8	M
Vessel 96	40	H	8	10	15	7	H
Vessel 97	34	H	10	7	10	7	H
Vessel 98	74	L	15	15	25	19	M
Vessel 99	34	H	8	10	8	8	H
Vessel 100	87	L	30	22	12	19	M
Vessel 101	87	L	30	16	22	19	L
Vessel 102	83	L	29	15	19	20	L
Vessel 103	58	M	16	12	16	14	H
Vessel 104	95	L	30	24	22	19	L
Vessel 105	39	H	10	10	8	11	H
Vessel 106	87	L	28	20	22	17	L
Vessel 107	41	H	10	12	15	4	H
Vessel 108	55	H	9	21	14	11	H
Vessel 109	41	H	11	18	8	4	H
Vessel 110	56	H	22	12	11	11	H
Vessel 111	90	L	24	24	25	17	L
Vessel 112	81	L	30	12	20	19	M
Vessel 113	54	H	18	18	12	6	H
Vessel 114	56	H	20	15	8	13	H
Vessel 115	98	L	30	25	25	18	L
Vessel 116	65	L	18	13	12	22	H
Vessel 117	56	H	8	16	11	21	H
Vessel 118	69	L	28	17	11	13	M
Vessel 119	87	L	28	24	16	19	L
Vessel 120	36	H	9	9	8	10	H

low risk based on the overall score, but it could still pose a high risk in terms of the safety of the crew or any of the individual sections.

To address this, a risk matrix, see Figure 6 and individual section limits, see Table 6 are developed or calculated, which provide a comprehensive understanding of the vessel's risk state. Figure 6[1,2,3] depict the final risk matrix designed exclusively for this study.

Table 6. Safety and Schedule Metrics

Section	Average	Standard Deviation	Upper Limit	Lower Limit
Safety of the crew (SOC)	17.85833	8.531604	19.38	16.33
Safety of the vessel (SOV)	15.075	5.832613	16.12	14.03
Safety of the cargo (SOCR)	15.525	5.900512	16.58	14.47
Schedule reliability (SR)	12.45833	5.903242	13.51	11.40

Based on this matrix, it is determined that if a vessel is classified as a high risk in any of the sections (safety of the crew, safety of the vessel, safety of the cargo, or schedule reliability), the overall risk categorization of the vessel is impacted, regardless of the overall score.

However, if a vessel is classified as a high risk in any two sections, it is considered a high risk vessel, regardless of the overall score. This approach ensures that the individual section risk weightage is taken into consideration when determining the final risk categorization of the vessel, giving priority to areas where significant risks are identified, regardless of the overall score.

8.2 BENCHMARKING THE SECTIONS

A similar methodology was employed to calculate individual thresholds for each section, namely safety of the crew (SOC), safety of the vessel (SOV), safety of the cargo (SOCR), and schedule reliability (SR), as described in Section 7.3 of this study. Once again, secondary data is utilized to determine the specific

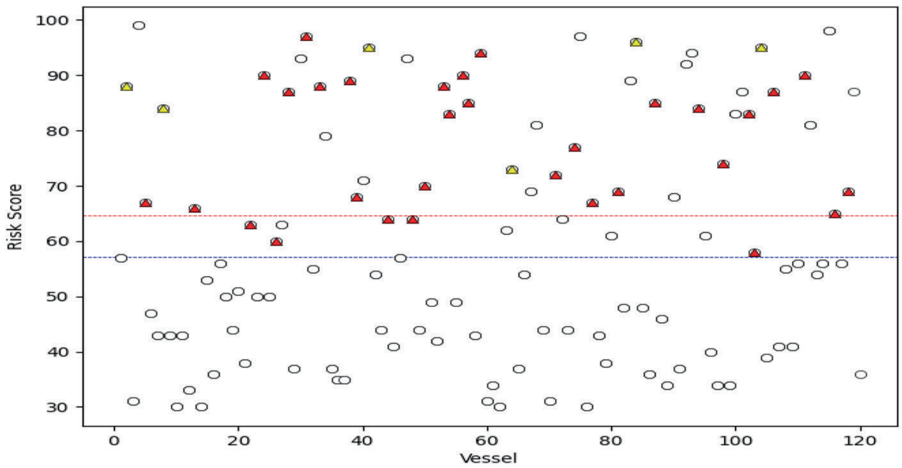

Figure 7. Change in Overall Risk

[1]Red Triangles indicate the vessels which have moved from Low to high risk or from medium to high Risk.
[2]Yellow Triangles indicate the vessels which have moved from low to medium risk.
[3]Circles with no colour are the vessels which remain unaffected
[4]Number of vessels which have changed the risk category from low to high risk is 26
[5]Number of vessels which have changed the risk category from low to medium risk is 6
[6]Number of vessels which have changed the risk category from medium to high risk is 5

thresholds for each section, which are then adjusted according to the data requirements of this study. Refer to Table 7 for the translated data and the resulting upper and lower limits, which are calculated based on the 95% confidence interval (1) For further details, see Table 6.

8.3 INTEGRATING FINAL RISK MATRIX

By applying the final risk matrix, see Figure 6 to the individual section scores, see Table 7, it has been observed that the count of high-risk vessels has increased from 61 to 73, representing a 16.44% increase. Similarly, the count of medium-risk vessels has increased from 10 to 18, indicating a 44.44% increase. On the other hand, the number of low-risk vessels has decreased from 48 to 29, reflecting a decrease of 68.97%. In total 31% of the vessels got impacted due to implementation of the final risk matrix. For a detailed overview, please refer to Table 7. Additionally, Figure 7[1,2,3,4,5,6]. illustrates the movement of vessels from their initial risk band as illustrated in Figure 5 to their newly assigned bands based on the implemented risk matrix.

9. CONCLUSION AND ACHIEVEMENTS

According to this study, assigning risk weightages solely based on an algorithm (1) may not provide accurate and reliable risk scores due to the presence of ambiguity. To obtain precise results, an alternative methodology called the Final Risk Matrix, (See Figure 6) is developed, which not only provides accurate outcomes but also helps identify the true nature of risk and addresses it at its core.

This study has achieved the following objectives:

- Identification of a potential scientific method for assigning weightages to individual ships and categorizing them as high, medium, and low risk.
- Application of Six Sigma methodologies [10] and the development of an algorithm, which was tested using secondary data.
- Alignment with the recommendations from the International Maritime Organization (IMO).
- Transformation of existing secondary data into the required format for this study.
- Formulation of metrics and an algorithm to assign weightages to individual vessels based on the RPN score.
- Designing a 5×5×5 risk matrix with well-defined limits to determine high, medium and low risk zones using Pareto analysis against a 4×4 matrix as described under MSC/Circ. 1023 [6].
- Creation of a single chart to monitor the overall safety performance of the entire fleet.
- Development of a unique risk matrix chart to assign the final risk to individual vessels.
- Real-world testing and collection of primary data from two vessels was carried out, which showed promising results.

This methodology can be further tested and implemented in various shipping organizations and classification societies. Increased data input will lead to more accurate results and enhance the identification of vessels that pose a true safety risk at sea. The author emphasizes the importance of vessel safety and highlights that by adopting such a statistical approach, a universal scale of measure may be established for assessing the true and accurate nature of risk across all vessels worldwide. In simple terms, it may also be stated that this study is a 2- step authentication process towards the true condition of the vessel.

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11. REFERENCES

1. AMSI. (2022) 4h: *Formal safety assessment*. Available at: https://amsi.org.au/ESA_Senior_Years/SeniorTopic4/4h/4h_2content_11.html (Accessed: December 7th, 2022).
2. EU Publication Office. (2022) *Cordis project information*. Available at: https://cordis.europa.eu/project/id/516278/reporting (Accessed: December 7th, 2022).
3. European Maritime Safety Agency. (2022) Publications. Available at: https://www.emsa.europa.eu/publications.html (Accessed: December 7th, 2022).
4. FARQUHARSON, J., McDUFFEE, J., SEAH, A.K., et al. (2002) *Fmea of marine systems: moving from prescriptive to risk-based design and classification*. In: Annual Reliability and Maintainability Symposium. 2002 Proceedings (Cat. No. 02CH37318), IEEE, pp. 165–172.
5. HÄNNINEN, M., BANDA, O.A.V., KUJALA, P. (2014) *Bayesian network model of maritime safety management*. Expert Systems with Applications, 41(17), pp. 7837–7846.
6. International Maritime Organization. *(2007) 83/INF. 2 formal safety assessment consolidated text of MSC/Circ. 1023-MEPC/Circ. 392*.
7. LINARDOU, V. (2022) *Vetting inspections*. PhD thesis, University of Piraeus (Greece).
8. MUNRO, R., RAMU, G., ZRYMIAK, D. (2015) *The Certified Six Sigma Green Belt Handbook*. Quality Press.
9. NOORAMIN, A.S., AHOUEI, V.R., SAYAREH, J. (2011) *A six sigma framework for marine container terminals*. International Journal of Lean Six Sigma, 2(3), pp. 241–253.
10. PURNAMA, D.A., SHINTA, R.C., HELIA, V.N. (2018) *Quality improvements on creative industry by using six sigma: A study case*. In: MATEC web of conferences, p. 01088.
11. RAPTODIMOS, Y., LAZAKIS, I., THEOTOKATOS, G., et al. (2016) *Collection and analysis of data for ship condition monitoring aiming at enhanced reliability & safety*. In: The 26th International Ocean and Polar Engineering Conference, OnePetro.
12. STATISTA. (2022) *Container Shipping - Statistics & Facts*. Available at: https://www.statista.com/topics/1367/container-shipping/ (Accessed: December 7th, 2022).
13. United Nations Conference on Trade and Development. *(2022) Review of maritime transport 2021.* Available at: https://unctad.org/publication/review-maritime-transport-2021 (Accessed: December 7th, 2022).
14. WANG, J., FOINIKIS, P. (2001) *Formal safety assessment of containerships*. Marine Policy, 25(2), pp. 143–157.
15. YANG, Z.L., WANG, J., LI, K.X. (2013) *Maritime safety analysis in retrospect*. Maritime Policy & Management, 40(3), pp. 261–277.