SHIP MAINTENANCE AND RISK ASSESSMENT THROUGH A SURVEY APPLIED TO SEAFARERS

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Abstract. *Safety is a major issue for the maritime industry and poor maintenance has been and remains one of the main causes of many incidents, although predictive maintenance methods have been progressively implemented on board ships over the last decade, in addition to the Planned Maintenance System (PMS).*
The main objective of the research is to provide a real overview of the types of maintenance applied to onboard equipment, and how it can improve the operational safety of ships, and at the same time protect seafarers and the environment. Considering these aspects, this paper presents the main results of quantitative research, developed through Google Forms, on ship maintenance and risk assessment in maintenance activities. By establishing a research framework and developing a questionnaire, much information was collected from seafarers with experience and responsibilities in maintenance. Results showed that predictive maintenance supersedes traditional maintenance programs for most of the onboard equipment and ships. Also, for a better implementation of these technologies related risk factors should be well-known and managed accordingly.

Keywords: *questionnaire, risk in maintenance, ship maintenance, survey.*

Introduction

One of the main elements of international trade is represented by the shipping industry, given that 85% of goods are transported using river or sea routes. Technological improvements have facilitated maritime transport development to reach this value. To reduce the risk of accidents, simplify the operation of the ship and increase the efficiency of maritime traffic, automatic equipment, and systems (*such as the Integrated Bridge System*) have been developed, onboard systems and machinery follow a strict maintenance protocol and procedures are revised to align with the new standards imposed by international law.

Usually, the life of a ship exceeds 25 years of operation. The role and importance of maintenance are constantly increasing, challenging both operational and management personnel to make proper arrangements for maintenance and always keep the ship in a safe and seaworthy condition.

The research identifies the current practices for ship maintenance and the risk factors in maintenance-related activities. It also provides a quantitative analysis of related maintenance activities and the degree of implementation of proactive maintenance for ship systems and determines the average level of risk factors identified from bibliographic research. The methodology used was a questionnaire-based survey of 46 respondents with theoretical and practical experience in the field.

The paper consists of four essential parts addressing the following issues: co-relation between safety and maintenance considering related literature and reports about maritime accidents, description of research objectives and conceptual framework for data collection, methodology of the research, and results after the analysis of the information collected and some directions for further direction of research.

Maintenance – a matter of safety for ships

To support the continuous growth of international trade, ships have experienced significant technological improvements regarding capacity transport, ease of operation, route management, and safety. More than 20.1% of container vessels and 31.2% of tankers have a GT>60,000. However, contrary to the widespread opinion that *a high level of automation means more safety*, technology can contribute to the occurrence of accidents caused by human error and therefore defeats the purpose for which it was introduced. (Bielic, 2017)

In a study regarding maritime accidents between 2002 and 2016, inappropriate/ineffective maintenance was identified as an overall cause of all types of accidents for about 12.1% of cases. Also, a fairly large percentage, 11.5% of cases, were produced because of a technique or equipment failure (Acejo, 2018).

Analyzing the data presented in Table 1, foundered (sunk/submerged) wrecked/stranded and fire/explosion are the top three causes of total losses over the past decade, accounting for 85% of all losses in the period 2010-2020, worldwide. (Allianz, 2020)

Since 2011, more than a third of reported incidents (around 9,334) were caused by machinery damage or failure – well over twice as many as the next highest cause, collision (3,288). For 2020, machinery damage/failure was the top cause of shipping incidents, accounting for 40%. (Allianz, 2020)

However, the perception that *technology is fully reliable* can lead to underestimation of risks and, consequently, to a change in attitudes toward good sea practice and standard procedures, thus allowing human error. According to several studies, these are just some of the causes of incidents caused by human error, which is the determining factor in the development of accidents in the maritime industry. (Schröder –Hinrichs et al. 2012; Ugurlu, 2015)

Table 1. Total losses by cause between 2011 and 2020 (Allianz, 2020, p. 14)

Total losses by cause	2011 2016	2017	2018	2019	2020	Tota l	Percent
Foundered (sunk/submerged)	334	57	31	31	24	477	54.45%
Wrecked/stranded (grounded)	135	15	11	4	7	172	19.63%
Fire/explosion	66	8	6	9	10	99	11.30%
Machinery damage/failure	39	9	2	-	1	51	5.82%
Hull damage (holed, cracks etc.)	22	5	1	1	-	29	3.31%
Collision (involving vessels)	21	1	2	1	2	27	3.08%
Contact (e.g., harbor wall)	3	-	-	-	-	3	0.34%
Missing/overdue	2	-	-	1	-	3	0.34%
Piracy	1	-	-	-	-	1	0.11%
Miscellaneous	8	-	-	1	5	14	1.60%
TOTAL	631	95	53	48	49	876	100%

At the beginning, corrective maintenance was the first strategy for maintaining ships at a satisfactory operation level. The demand for larger transport capacity and accidents such as the Tory Canyon determined major changes in the structure of ships to improve safety and lower the risk to the marine environment (Hawkins, 2017). Also, preventive programs were imposed by I.M.O, in addition to corrective actions.

Now the maritime industry implements a predictive program that assesses the state of the equipment and applied maintenance procedures to prevent breakdown.

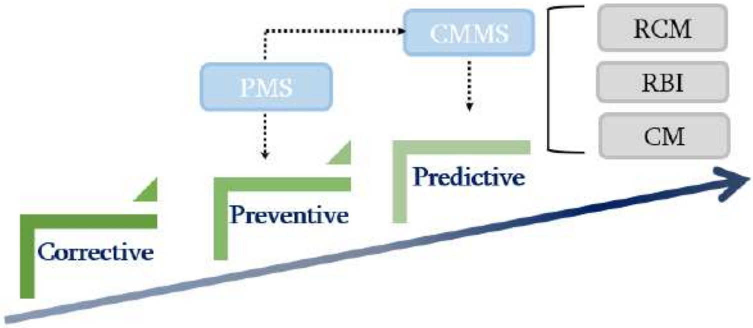


Figure 1. The evolution of the maintenance process in the shipbuilding industry (adapted from Lazakis, 2010)

In figure 1, predictive maintenance is divided into three categories: reliability-centered maintenance-RCM, risk-based inspection-RBI, and condition monitoring-CM (Lazakis, 2010). Preventive and predictive maintenance methods have evolved by implementing IT solutions to manage the maintenance process. Considering all of the above, an optimized maintenance program will focus on extending equipment lifespan, optimizing downtime, reducing costs, and improving safety. (Simion. 2021)

Theoretical aspects regarding the present study

The overall objective of this study is to identify opportunities to improve maintenance for ship systems by evaluating current practices and risk factors in maintenance. In this regard, a conceptual framework (*an action plan*) has been developed in accordance with the Formal Safety Assessment (FSA) method and IMO regulations in this area (IMO FSA, 2018). The research was structured in two stages, as presented in figure 2. In the first stage, the research's authors synthesize the internal and external sources of information from the literature (Nicolae, 2020). Three directions of the research are outlined:

- main systems on board the ships;
- current maintenance practice and level of implementation for predictive maintenance;
- risk factors in maintenance.

This stage is based on the analysis of relevant literature and documents in maritime, engineering, energy, industrial, and offshore maintenance, from 2010 to 2021, using the "free consultation" resources available online. A finding is that for the maritime sector Failure Mode, Effects, and Criticality Analysis (FMECA) and Fault Tree Analysis (FTA) are the main techniques used for risk assessment (Simion, 2021).

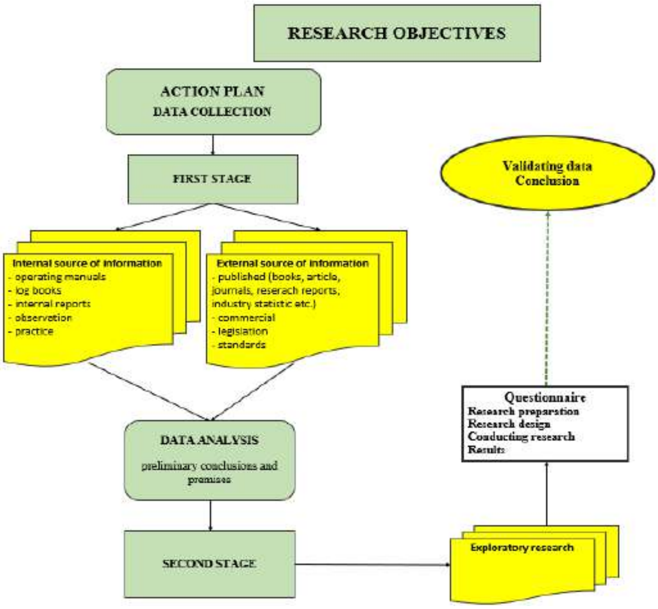


Figure 2. Sources of data collection
(adapted from Nicolae, 2020)

As some issues identified in the theoretical study could not be clearly defined and included in the ship maintenance, the second stage is necessary as exploratory research to consult technical specialists in maritime transport. The second stage considered appropriate for using techniques and methods derived from market research, begins with some theoretical aspects, as presented in Figure 3.

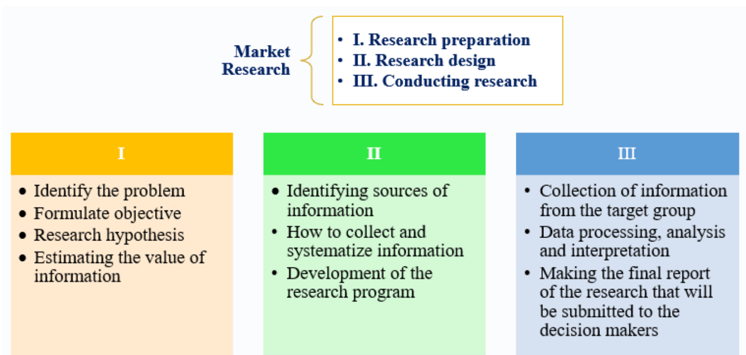


Figure 3. Stages of market research
(source: personal interpretation based on Cătoiu, 2002 and Adams, 2007)

The research methodology used was a questionnaire-based survey, which was designed to perform descriptive and inferential analyses of the data collected. The questionnaire is a useful tool for identifying risks in the maritime field and is often used on board ships to improve safety practices and to develop operational procedures.

The answers offer a detailed picture of the following aspects, which represent the research objectives:

- the current state of implementation for different maintenance policies;
- maintenance particularities for onboard equipment;
- possibility of improving maintenance to increase system reliability and operational safety;
- variables for establishing the critical level of equipment;
- determination of critical ship system and equipment.

After data processing \,the results will further provide a deep understanding of critical mechanisms and systems on board the ship and their current state regarding operation and maintenance. The research conclusions will be used to develop further risk assessment applications for increasing ships' equipment's safe operation.

The methodology of the research

A survey regarding maintenance policies implemented onboard ships and risk management in ship maintenance was conducted. The research intended to demonstrate that only some risk management methods are used in shipping, and critical analysis for onboard equipment is needed to prioritize maintenance tasks. The research problem is as follows – *What are the current state of maintenance and related risk factors for onboard equipment and what will be the course of action to increase system reliability and operational safety?*

Preliminary conclusion after completing the first stage set the foundation for developing a questionnaire based on the next seven premises:

- P1. the technical expertise of onboard personnel increases with the transition to the managerial level (over 7 years experience);
- P2. on board ships predictive maintenance is applied in addition to corrective and preventive program but not all predictive maintenance techniques are applied on board ships;
- P3. the high technological level of ships implies the adoption of modern maintenance techniques;
- P4.some factors that contribute to the low implementation of predictive maintenance;
- P5. there are risk factors in maintenance that may adversely affect the equipment and safe operation of ships;
- P6. for onboard equipment should be an assessment of criticality for setting priorities in maintenance activities;
- P7. the main risk assessment methods (FTA and FMECA) used mainly in the literature must be applied in practice.

The questionnaire was divided into four sections, with 18 questions, as follows:

- Section I: four questions about respondent profiles and recent activity

- Section II: one question for assessing the level of application for existing maintenance policies and eight statements to determine whether some of the conclusions of the maintenance studies are also valid for naval equipment;
- Section III: four questions for assessing the degree of implementation for predictive maintenance methods for onboard equipment
- Section IV: eight questions regarding risk management in maintenance activities for onboard equipment.

Open-ended questions were used to formulate the answer to achieve the responding specialists' appropriate profile and the maintenance activities' particularities, and closed-ended questions with a single answer, respectively, with multiple answer options.

Identifying and exploiting the interdependencies between the defined variables were analyzed and interpreted using the IBM SPSS Statistic software tools. Thus, based on the data collected during the research, the variables were defined in the IBM SPSS Statistics Data Editor program, the modules "Variables view" and "Data view" resulting in a document with the extension sav that allowed: database management, data recording, variable analysis research and centralization of data in tabular and graphical form. (Pallant, 2011)

The research on the current state of maintenance and risk assessment for on-board equipment was initiated on a sample of 46 respondents, staff with theoretical and practical experience in the maritime field, operational and managerial areas (second officers, captains, chief engineers) and experts in the field of maintenance (engineers, superintendents, university professors) specialists in the field of ship repair, inspectors of naval classification registers. The questionnaire was applied between 01.03-31.03.2022, through the Google Forms platform.

Results and discussion

At the end of the response collection period, the data were added and processed in the IBM SPSS Statistics Data Editor. Five respondents did not provide complete answers to the mandatory questions (sections III and IV), and these data were not processed. The data are interpreted in the same order as they appeared in the questionnaire available at https://forms.gle/bpZdebqutNdd1G8BA

Results for the first section of the questionnaire

The purpose of the first section of the questionnaire was to collect data on the profile of the respondents and recent activities in the maritime/shipping industry. The first question was to collect the email address to validate the unique participants because the questionnaire was published online and there could be multiple answers. The results of the next two questions in this section are summarized in table 2.

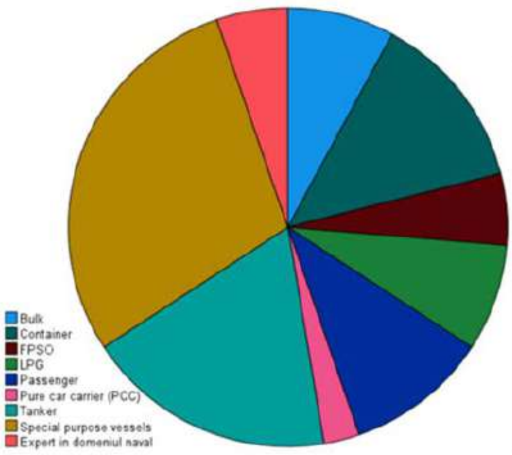
Table 2. Details about the group sample used for the study

Question	Frequency	Percent
2. Professional experience		
Under 7	9	22%

Question	Frequency	Percent
Between 7 to 15	15	36.6%
Between 15 to 25	8	19.5%
Over 25	9	22%
TOTAL	41	100%
3. Ships age		
Under 7	9	22%
Between 7 to 15	18	43.9%
Between 15 to 25	5	12.2%
Over 25	9	22%
TOTAL	41	100%

Regarding the age of the ships in which they carried out their activity, it is observed that more than 65% have experience on board ships under 15 years, in other words, in most of their professional career they have operated new generation equipment and systems at the time of embarkation, ships with a high degree of technology and safety.

The fourth question, with an open answer, aimed at identifying the types of vessels on which the respondents carried out their professional activity. Given the broad classification of ships, some responses were grouped into the class of special vessels (technical vessels, tugs, military vessels, offshore support vessels) and accounted for 26% of the total responses. The other types of ships can easily fall into the general category of cargo ships (bulk cargo, liquid bulk cargo, containers) and passenger transport. Figure 4 shows the percentage and frequency of the answers provided.



		Frequency	Percent
Valid	Bulk	3	7,3
	Container	5	12,2
	Container, Oil-Chem Tanker, PSV, AHTS, DSV, PL, OSV	1	2,4
	Expert in domeniul naval	2	4,9
	FPSO	2	4,9
	LPG	3	7,3
	Passenger	4	9,8
	Pure car carrier (PCC)	1	2,4
	Special purpose vessels	11	26,8
	Tanker	7	17,1
	Tanker, LPG tanker, Oil/Chem/LPG, OBO, PSV, AHTS	1	2,4
	TANKERS, LNG, CRUISE LINERS	1	2,4
	Total	41	100,0

Figure 4. Answer distribution for ship type

The respondent's profile, depending on the vessels' age and experience, can be observed from the data presented in Figure 5. Given that respondents with more than 7 years of experience working on new generation ships (less than 15 years old) represent more than half of the total, we can say that their technical expertise is relevant and provides a detailed image of the maintenance process for ship systems with a high degree of automation. Also, about 30% of respondents worked on ships that carried dangerous goods (oil tanks, chemical tanks, FPSO, and LPG) where legislation imposed high safety standards for onboard equipment and crew training (Figure 4).

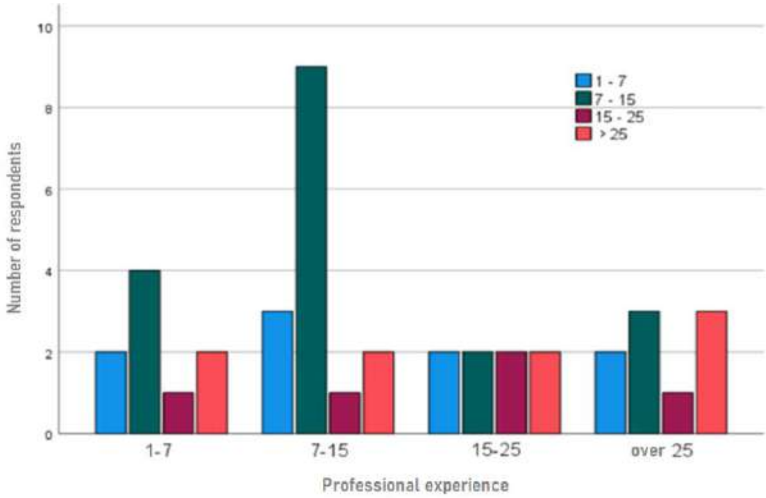


Figure 5. Profile of the respondents

Results for the second section of the questionnaire

The next question assesses the overall level of implementation for different maintenance policies. The process of transforming maintenance into a predictive system is still in progress in this area, and the degree of implementation is different. According to the distribution of answers in Figure 6, the predictive maintenance system is applied mainly to ships 1-15 years old, 27 of the respondents confirmed that there is a certain degree of implementation, as part of the classic maintenance program (corrective and preventive). Simultaneously, there is a low level of implementation for ships over 25 years old, explained by the fact that a large part of them must be upgraded to extend class certificates and operating resources. Additionally, upgrading of some types of vessels (oil tanks, offshore support vessels) must align with the new safety and environmental standards.

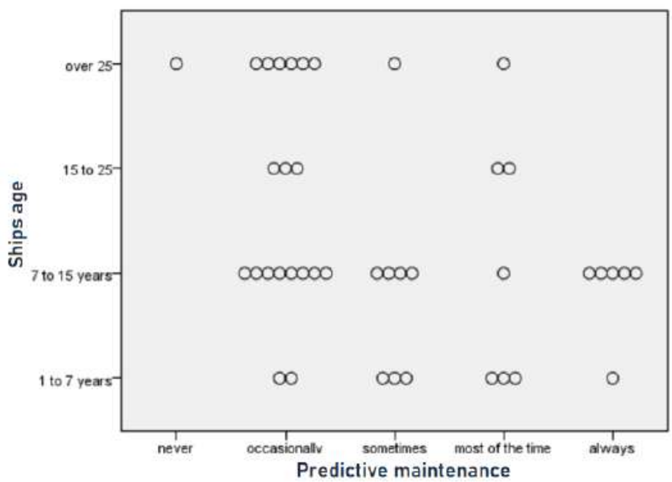


Figure 6. Overall level of implementation of predictive maintenance

The main objective of the second section was to determine whether some of the conclusions of the maintenance studies are also valid for naval equipment and onboard systems. In this regard, respondents assessed, on a scale of 1 to 10, to what extent the eight statements apply in their field of activity. The statistics are presented in Table 3.

Table 3. Response statistics for statements A1 to A8

Statistics	A.1	A.2	A.3	A.4	A.5	A.6	A.7	A.8
Mean	7,51	7,00	5,39	8,59	8,12	7,85	6,39	8,12
Median	8,00	8,00	6,00	9,00	8,00	9,00	7,00	9,00
Mode	7	8	6	10	10	10	8	9
Std. Deviation	2,135	2,711	3,032	2,073	2,064	2,383	2,783	2,088
Variance	4,556	7,350	9,194	4,299	4,260	5,678	7,744	4,360
Skewness	-1,526	-0,807	-0,076	-2,029	-1,463	-1,076	-0,440	-1,677
Std. Error of Skewness	0,369	0,369	0,369	0,369	0,369	0,369	0,369	0,369
Kurtosis	2,678	-0,526	-1,335	3,607	2,464	0,216	-0,893	2,628
Std. Error of Kurtosis	0,724	0,724	0,724	0,724	0,724	0,724	0,724	0,724
Minimum	1	1	1	2	1	2	1	2
Maximum	10	10	10	10	10	10	10	10

A symmetrical distribution of responses (Skewness with values close to 0) is observed for statement A3 - For equipment with a high degree of redundancy (pumps, fans) maintenance can be delayed without significantly affecting the operation of the ship and statement A7 - Works Maintenance performed too often (over maintenance) does more harm than good. The other statements have an asymmetrical distribution of answers, with a negative distortion.

Results for the third section of the questionnaire

This section assesses the degree of implementation for predictive maintenance methods beginning with the seventh question, *"Which proactive policies are part of the maintenance program onboard."* Condition-based maintenance (CBM) is presented in 20 responses followed by Risk-Based Maintenance/Inspection (RBM/RBI) in 18 responses. At a low level, 11 responses are for Reliability-Centered Maintenance (RCM) and Total Productive Maintenance (TPM). Also, two of the responses are for not applying proactive maintenance onboard.

Next, respondents had to assess the extent to which predictive (proactive) maintenance is part of the on-board maintenance program and the information is summarized in Table 4.

Table 4. Degree of implementation of proactive maintenance for onboard system and equipment's

Evaluation scale	Main engine propulsion system		Generators (DG, TG, SG)		Steering gear		Boilers (steam system)		Compressed air sys., CO_2, inert gas	
	No	%	No	%	No	%	No	%	No	%
Poor	1	2,44	2	4,88	3	7,32	3	7,32	4	9,76

Fair	4	9,76	3	7,32	6	14,63	8	19,51	10	24,39
Average	9	21,95	10	24,39	9	21,95	10	24,39	12	29,27
Good	18	43,90	17	41,46	16	39,02	13	31,71	9	21,95
Excellent	9	21,95	9	21,95	7	17,07	7	17,07	6	14,63
Total	41	-	41	-	41	-	41	-	41	-

Evaluation scale	**Navigation equipment**		**Deck systems**		**Life-saving appliances**		**Cargo handling equipment**	
	No	**%**	**No**	**%**	**No**	**%**	**No**	**%**
Poor	3	7,32	2	4,88	2	4,88	2	4,88
Fair	6	14,63	8	19,51	9	21,95	7	17,07
Average	11	26,83	14	34,15	6	14,63	9	21,95
Good	11	26,83	9	21,95	14	34,15	14	34,15
Excellent	10	24,39	8	19,5	10	24,39	9	21,95
Total	41	-	41	-	41	-	41	-

The data confirm that predictive maintenance is applied to various machinery and ship systems, with more than 35% for the propulsion system, electric system, and steering gear. For navigation equipment, we have a low level of implementation, true because of the construction characteristics of this equipment (most of them are non-repairable components and maintenance must be replaced after breakdown).

Analyzing the responses to the ninth question confirmed what most research articles and projects shown, that proactive maintenance can increase the reliability of the equipment. By processing the answers and tracing the histogram in Figure 7, an asymmetric distribution of the answers on the right and an average rank of 9 (on a scale from 1 to 10), which confirms, through the experience of respondents, the true value of this statement for the maritime domain.

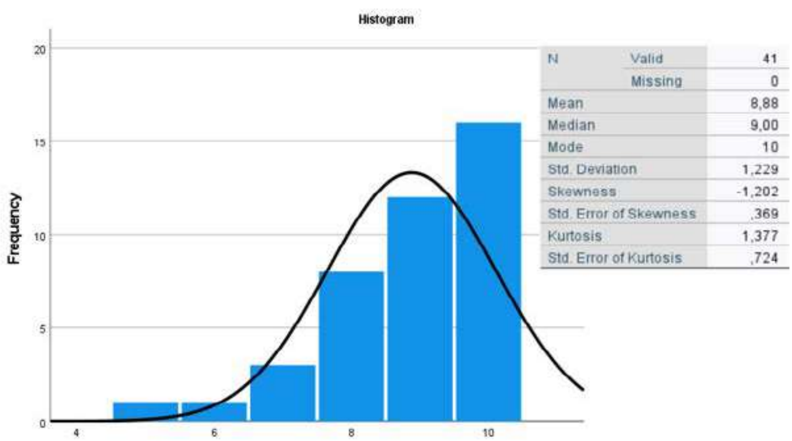


Figure 7. Histogram for question 9

The last question in this section focuses on the factors that contribute to the low level of implementation of predictive maintenance, although the benefits in other areas of activity are significant. Respondents assessed the main contributing factors and the percentage analysis is presented in Table 5.

Table 5. Factors for a low level of predictive maintenance implementation

Factors	Sometimes (%)	Most of the time (%)	Always (%)
Lack of procedures or implementation guidelines	41,46	31,71	2,44
High installation costs	26,82	41,46	17,07
Lack of technical training	36,58	29,26	12,19
Company management	29,26	34,14	17,07
Improper use of condition monitoring data	24,39	24,39	7,31

Results for fourth section of the questionnaire

The last section contains eight questions for collecting data for the detailed stability of certain categories of maintenance risk management. Question 11 proposes maintenance risk factors for evaluation.

By analyzing and evaluating the specific activities in the naval field, three main components of the maintenance system (human resource, maintenance process, and maintenance system) were established and 15 risk factors were identified:

- Risk factors H.1 – H.5 (human resource);
- Risk factors P.1 – P.5 (maintenance process);
- Risk factors S.1 – S.5 (maintenance system).

Thus, following the evaluation of the answers, the average values for the frequency of occurrence and impact were obtained for each risk factor. These values correspond to an average level for both frequency and impact. However, to determine the level of risk exposure in maintenance activities, risk indices were generated as a product of the two elements of each identified risk factor, using the syntax editor of the IBM SPSS Statistics.

Based on the results obtained from calculating the exposure level, the risk profile of the three components was created using two tools specific to risk analysis: a radar diagram (figure 8) and a risk matrix (figure 9).

Figure 8. Radar diagram for risk factors (IBM SPSS Statistics)

Using the risk matrix, it is observed how the risks are distributed in the three areas marked using representative colors (green, yellow, and red) to mark the severity of the risk. The average values of the overall risk indices were obtained:

- The human resource component has a frequency of 3.23 (very possible) and an impact of 3.44 (major);
- The process component has a frequency of 3.24 (very possible) and an impact of 3.55 (major);
- The system component has a frequency of 2.83 (very possible) and an impact of 3.40 (major).

The data show a high level of symmetry on the three components of risk for naval maintenance.

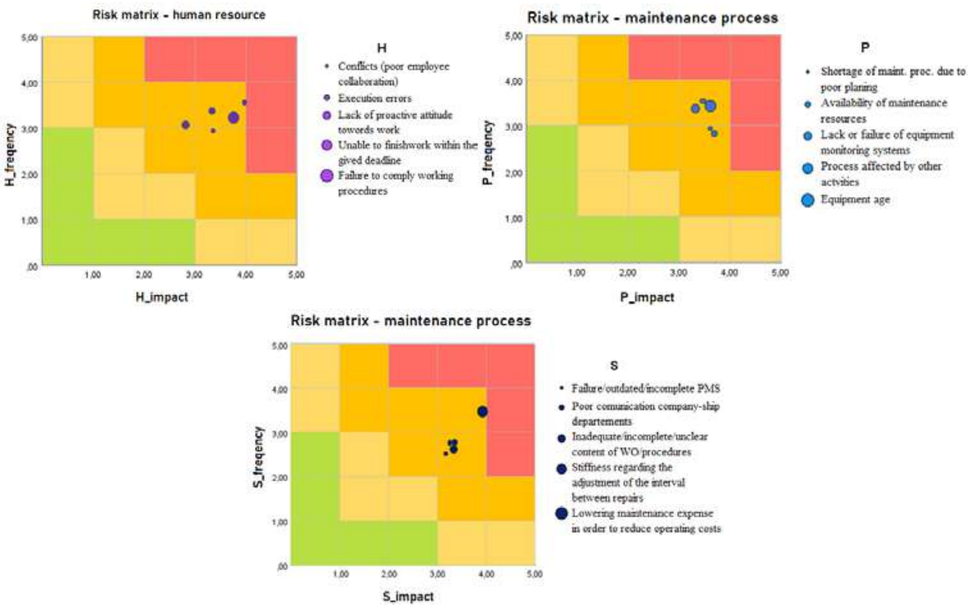


Figure 9. Matrix for risk factors

The next two questions address the criticality analysis issue for naval equipment. The purpose of a criticality analysis is to determine the level of risk associated with each failure as a combination of the likelihood and consequences to prioritize maintenance activities and measures to improve reliability.

Table 6. Critically analysis factors for onboard equipment

Factors	Rarely (%)	Occasionally (%)	Sometimes (%)	Most of the time (%)	Always (%)
Impact on ship operations	-	12,2	7,3	34,1	46,4
Environmental impact	7,3	2,4	22,0	31,7	36,6
Cost of maintenance activities	2,4	12,2	31,7	34,1	19,6
Redundancy level of equipment	2,4	14,6	19,6	39,0	24,4
Cost of equipment	2,4	7,3	29,3	36,6	24,4
Age of equipment	4,9	7,3	31,7	34,1	22,0
Reliability of equipment	-	17,1	26,8	22,0	34,1
Spare parts availability	7,3	4,9	14,6	31,7	41,5
Availability of monitoring technology	-	19,5	17,1	43,9	19,5

Over 80% of respondents said that criticality analysis is used for naval equipment. The five most important factors to consider when ranking equipment in terms of the risk of failure are in descending order of importance, those related to the safety of navigation and environmental protection, diagnostic possibilities, availability of spare parts, and the level of redundancy and similar on-board equipment; the statistical analysis of the answers are presented in table 6.

The following three questions were aimed to identify the main systems and equipment on board, in terms of the following:
• increased failure rate (question 14);
• low-failure rate/high reliability (question 15);
• the impact on the ship safe operation in case of failure (question 16).

Table 7. Statistical analysis of the failure rate for onboard equipment

Factors	Q 14 (high failure rate)		Q15 (low failure rate)		Q 16 (greatest impact on ship safe operation)	
	No	%	No	%	No	%
Main engine and propulsion system	11	**13,25%**	9	**13,85 %**	23	**23,47%**
Generators (DG, TG, SG) / main switchboard	13	**15,66%**	7	**10,77 %**	22	**22,45%**
Steering gear	5	6,02%	8	**12,31 %**	19	**19,39%**
Boilers (steam distribution system)	4	4,82%	3	4,62%	5	5,10%

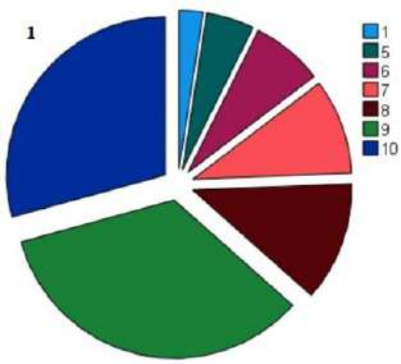
Factors	Q 14 (high failure rate)		Q15 (low failure rate)		Q 16 (greatest impact on ship safe operation)	
	No	%	No	%	No	%
Pressure system	5	6,02%	3	4,62%	-	
Navigation equipment	1	1,20%	-		-	
Deck equipment	4	4,82%	2	3,08%	-	
Life-saving appliances	1	1,20%	2	3,08%	1	1,02%
Cargo handling system (2)	6	7,23%	3	4,62%	7	7,14%
Pumps, valves, fittings (3)	12	**14,46%**	1	1,54%	3	3,06%
Ballast system	2	2,41%	3	4,62%	2	2,04%
Separators/purifiers	5	6,02%	2	3,08%	-	
Bridge equipment (4)	4	4,82%	6	9,23%	4	4,08%
Other electrical equipment (5)	10	12,05%	2	3,08%	-	
Fire safety appliances (6)	-		5	7,69%	5	5,10%

(1) Compressed air, CO2, inert gas, refrigeration systems
(2) Cranes, liquid-cargo discharge pump, davit, DP systems
(3) Pumps, valves, fittings
(4) Radar, ECDIS, GPS
(5) General alarm system, auxiliary switchboard, fans
(6) Maine fire line

The open-ended questions allow evaluators to develop the best possible answers given their experience and knowledge in this field. The statistical analysis of the answers is presented in Table 7. More than 75% of answers included two or more systems/equipment. Two types of equipment were observed at the top of respondents' preferences: main engine and propulsion system and power generators/power plant.

The reason for including these three questions in the survey was to establish the priority level of the ship's equipment and systems from the perspective of maintenance activities. If the first two questions concerned the failure rate and reliability, several pieces of equipment on board ships are found, the answers to the last question are oriented in three main directions: energy systems (propulsion, electrical, steam), cargo installations, and security systems. Additionally, validates the importance of these systems for safe navigation. In conclusion, maintenance resources and activities should focus on non-redundant critical equipment (the main engine and steering gear are unique on board) and safety navigation equipment.

The section ends with two questions about the main risk assessment methods, FTA and FMECA, used in the literature. The statistical analysis and graph of the distribution of answers are presented in Figure 10.



		Frequency	Percent
Valid	1	1	2,4
	5	2	4,9
	6	3	7,3
	7	4	9,8
	8	5	12,2
	9	14	34,1
	10	12	29,3
	Total	41	100,0

		Frequency	Percent
Valid	1	1	2,4
	3	3	7,3
	5	3	7,3
	6	1	2,4
	7	6	14,6
	8	7	17,1
	9	7	17,1
	10	13	31,7
	Total	41	100,0

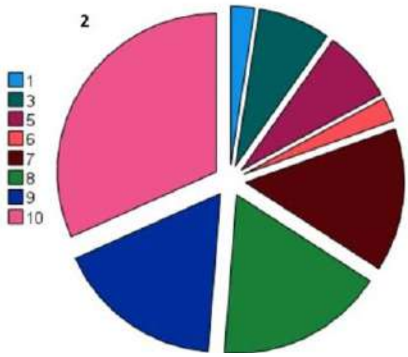


Figure 10. Opportunity to use FTA and FMECA for onboard equipment (17th and 18th question)

Thus, on a scale of 1 to 10 (where 1 represents total disagreement and 10 total agreement), respondents assessed the value of the benefits that FTA and FMECA methods can bring to maintenance (question 17) and the opportunity to develop applications that use these techniques to identify possible ways of failure for the safe operation of the ship's equipment (question 18). More than half of the answers agreed that there are benefits and that they can be used in practice in ship systems by developing dedicated applications.

Discussion and conclusions

The study's results bring to attention details about maintenance activities for onboard equipment using a questionnaire-based survey. The questionnaire structure and content facilitated clear responses from the specialists and validated the research premises.

First, the results show that most of the statements regarding general maintenance are also true for the maritime domain. The highest values are for the quality of maintenance work and resources and for the efficient checklist method onboard ships and in maintenance-related tasks. Questions about predictive maintenance reveal that these methods are implemented on a different level, regarding the type/age of the ships and the importance of equipment on ship operation. Maintenance management should focus on lowering the level of identified factors to adopt predictive policies for most of the equipment. Also, some measures will be needed to adapt the interval between repairs to a better resource and spare parts management.

Second, the risk of maintenance activities was also brought to attention in this article. The results show that all 15 risk factors identified have high values on a low-extreme scale for consequence and probability. Maintaining these factors at a minimum level is important to improve reliability, availability, efficiency, and quality and to protect the environment and personal maintenance.

Another research point was to classify the systems regarding failure rate and reliability and the importance of criticality analysis to prioritize maintenance tasks and resources. Results reveal that maintenance resources and activities should focus on non-redundant critical equipment (main engine and steering gear) and power generators.

The research limitations are related to the relatively small sample of respondents. However, their technical expertise is relevant and provides a detailed picture of the maintenance process for ship systems with a high degree of automation. Also, the questionnaire can be regarded as a pilot study and give a basis for extended research related to shipping maintenance.

Another direction for further research is to identify possible ways for using risk assessment methods, like FTA and FMECA, for the safe operation of the ship's equipment and developing dedicated applications for planning and executing maintenance-related tasks.

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