Ship Dynamic Maintenance – Risk Analysis

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Abstract. Considering the extent of the Portuguese sea and the naval ships necessary for its monitoring, the implementation of a maintenance system addressing those ships condition monitoring, is needed. That system must guarantee, also, a high performance of ships and systems availability, reduced pollution control, lubricants, refrigerant gases and marine gasoil consumptions. To achieve all this, a dynamic maintenance management system (DMMS) based on a dynamic management of technical interventions is required. In this paper some risk analysis maintenance techniques are explored, and the most applicable ones will be applied to selected ship equipment. In the present research, a case study of a specific equipment is presented and the corresponding risk analysis in maintenance context is studied. The case study illustrates the importance of having a dynamic maintenance system allowing to act when needed, and, in case of no action, the risk of non-maintenance. To validate our theory the research results and its analysis will be highlighted, and, finally, some conclusions are presented.

Keywords: Maintenance, Dynamic, Ship, Risk.

1 Introduction

The maritime domain, particularly the vast extension of the Portuguese sea, presents unique challenges for ship maintenance and operations. The importance of a robust maintenance system to ensure effective monitoring and security of naval ships, cannot be overstated. This paper deals with the concept of dynamic maintenance, integrating risk analysis techniques to enhance ship performance, reduce resource consumption, and mitigate environmental impact.

Ship maintenance is a vital process to ensure safety, reliability, and efficiency of maritime operations. It involves a variety of activities, from regular inspections and routine repairs to more complex interventions.

Preventive maintenance is essential to prevent failures and maximize the useful life of onboard equipment and systems, while corrective maintenance deals with unforeseen problems that arise during operation. With the advancement of technology, predictive maintenance has gained prominence, using sensors and data analysis to predict failures and schedule interventions before they occur.

Additionally, maintenance on ships faces unique challenges such as constant exposure to the elements, corrosion and wear caused by the marine environment. Therefore, effective and efficient maintenance strategies must consider these factors as well as strict maritime safety regulations. Efficient maintenance management not only reduces accidents and downtime risks but contributes also to operational and economic sustainability of vessels.

The aim of the present study is risk assessment on ships equipment considering an active or Dynamic Maintenance Management System (DMMS).

2 Maintenance System Risk Analysis Techniques – an Overview

This section provides an overview of current maintenance systems based on risk analysis and the shortcomings they present in addressing the dynamic needs of maritime operations. It presents the need for a proactive and dynamic approach to maintenance, highlighting the benefits of real-time monitoring and intervention.

Various risk analysis techniques applicable to maintenance activities are explored in this section. From Failure Mode and Effects Analysis (FMEA) to Reliability Centered Maintenance (RCM), each technique has advantages and limitations which are discussed from the point of view of maritime applications.

Dynamic maintenance, being a form of condition based maintenance (CBM), is essentially a data driven maintenance policy; it plays a crucial role in ensuring reliability, safety, and operational efficiency of complex systems in diverse sectors, from the automotive industry to aviation and the energy industry. In a scenario where component failure can have significant consequences, it is essential to adopt proactive approaches to identify and mitigate potential failures before they occur. In this context, Failure Mode Effect and Critical Analysis (FMECA) emerges as a powerful tool.

2.1 Dynamic maintenance and risk management

“Dynamic maintenance includes the operations (to large scale service components in the runtime. The dynamicity of maintenance means that the maintenance will not affect the execution of existing components and promise the downtime as less as possible.

Normally the maintaining requests are delivered by the administrators and provisioning modules” usually based on condition monitoring (Jin et al, 2009).

If the pair: dynamic maintenance is referred, the condition control monitoring will be a pillar of it.

Frequently maintenance can be carried out on board with the ship sailing normally, but many maintenance actions are carried out on harbors. This means that maintenance opportunities can be irregular so the economic dependency between spare parts and equipment’s, and its state must be determined to determine the best time to procced to an intervention (Young et al, 2023).

A dynamic risk assessment may be used to assess risk of maneuvering in restrict waters by ships (Mehdi et al, 2019), but also a risk assessment for a dynamic maintenance can be used in ships.

Static risk analysis may not be the right for a dynamic maintenance system (Kanj et al, 2022), so a dynamic risk analysis where some parameters or condition control are integrated may be the ideal.

Implementing a dynamic reliability analysis, it will promote maritime safety and protect the environment in general (Dikis et al, 2017).

By permanent installed sensors, like accelerometers to measure vibrations we can collect data online to provide information of a potential damage, so the correction action can be planned (Apeiranthitis et al, 2024).

The monitoring of propulsion systems on ship may contribute for reducing pollution emissions and support maintenance decision on the related equipment´s (Liu et al, 2022).

Preventive maintenance in the ship’s hull can enhance the ship maneuvering and decreases the losses of velocity contributing for reduce the fuel consumption during navigation.

Minimizing downtime in ships auxiliar equipment’s, are meaningful for correct functioning of main engines, for that the reliability monitoring is used to critical analyzing the equipment´s state (Daya, 2023).

In a concept of dynamic maintenance, the FMECA methodology may be used to define not only to define the equipment state but also to determine when to proceed to a maintenance intervention.

2.2 FMECA systems

FMECA is a systematic methodology that aims to identify component failure modes, analyze the effects of these failures, and prioritize mitigation actions based on the potential impact on the system. By applying FMECA, engineers or other technicians can anticipate potential failures in a system, understand the underlying causes, and develop effective preventive and corrective maintenance strategies. (Catic & Glisovic, 2019)

The FMECA may offer a structured approach to evaluating and managing the ongoing performance of systems in operation. Instead of relying exclusively on scheduled or reactive maintenance, FMECA allows organizations to identify areas of greatest risk and allocate resources more efficiently, prioritizing maintenance where it is needed most. (STAMATIS, 2003)

The original FMECA is calculated using equation nr 1. Where the O it's the probability of occurrence, S the severity and D de detection facility (STAMATIS, 2019).

$$RPN_{DM}=O*S*D \tag{1}$$

This article sets out to explore the application of FMECA in dynamic maintenance at complex systems, applying it to a case study and analyzing the resulting benefits. It will be checked if FMECA into existing maintenance processes will be an opportunity of enhancing when associated with another techniques.

3 Methodology in Ship Dynamic Maintenance

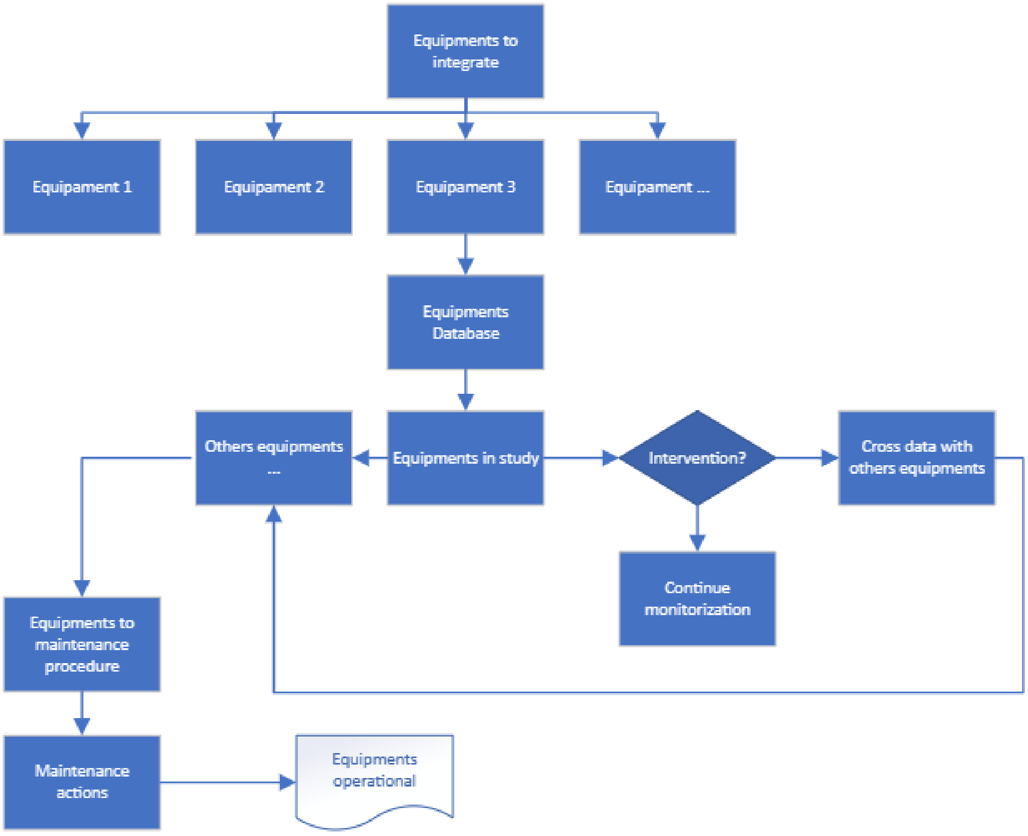

Fig. 1. Dynamic Maintenance Methodology

The next detailed case study exemplifies the implementation of a dynamic maintenance system on a selected ship equipment through FMECA. Observing real equipment data and operation scenarios, the effectiveness of proactive maintenance strategies may be demonstrated, emphasizing the value of timely intervention and risk mitigation, also through condition control data.

To determine the risk involved in equipment operation it was calculated the FMECA at first with the traditional concept. The calculus was made with equation nr 1. Where the O it's the probability of occurrence, S the severity and D de detection facility. (Lampreia et al, 2023)

$$RPNDM=O*Sm*D \qquad (2)$$

The difference from the original concept of severity in FMECA is that there were considered 5 Severities: Safety, Environmental, Equipment, Personnel, Operational; With it was calculated the mean: St=mean (SS; SE ; Seq; SP; SO).

Then it was decided to complement the FMECA with the equipment control condition (CC), which it was called FMECA-CC. Besides the original parameters it was considered the equipment's condition control, so it was integrated in the original equation four condition control parameters (control condition for vibration (CCV)(Vibration in Root mean Square (RMS) values); control condition for thermography (CCT) and control condition for text (CCTex) from SRTD is considered for respective equipment)

To calculate FMECA-CC it was used equation nr 3, applying the logarithmical function with neper base for reduce the dimension of the result values:

$$\text{FMECA-CC}=\text{LN}(O*Sm*D*(CCV*CCT*CCP*CCTex) \quad (3)$$

4 Research Findings and Analysis

This section presents the results of the research conducted, analyzing the performance and efficacy of the developed dynamic maintenance system. Quantitative and qualitative data were utilized to evaluate the system's impact on ship performance, resource consumption, and environmental sustainability.

After applying the FMECA methodology with condition control in electromechanical equipment on military ships, it was expected to obtain substantial results on reduction in the failure rates of the equipment understudy, directly reflecting on the operational reliability of the Navy military vessels.

To calculate the FMECA and FMECA-CC, it was considered 6 levels of severities, occurrence and for detection, and for the control condition five. To build categorization of FMECA and FMECA_CC it was considered the valuation on Table 1 equal for both concepts, so it can be fair compared.

Table 1. FMECA_CC Categorization

Linguistic term (Risk level)	Abbre-viation	Description	Classification	Procedure
Not critical	Nc	Risk is totally controlled	[0, 5[	Continue with the monitoring procedure
Semicritical	Sc	There is a little preoccupation about the equipment and system state	[5, 8[	Check for eventual enhance of the monitoring system
Critical	C	There are some preoccupations about the critic equipment/system situation	[8, 10[	Reinforce condition control monitoring
Very critical	Vc	The equipment/system are in a very critical situation	[10, 12]	Study opportunity for eventual maintenance, and check for needed spare parts

Table 2. Maintenance activity, aspect, impact and how to detect.

Nr	LOW PRESSURE AIR COMPRESSOR/MAINTENANCE ACTIVITY	Aspect	Impact	How detect
1	Clean the air filter. (Perform every 1000 hours of operation)	Filter with impurities	Entry of impurities into the internal compressor.	Clogged filter, low compression pressure
2	Clean the air filter. (Perform every 1000 hours of operation)	Filter with impurities/Air compressor system with impurities	Compressor damage	Internal inspection of the compressor if it is impossible to detect damage by visual inspection or non-destructive testing.
3	Clean the air filter. (Perform every 1000 hours of operation)	Filter with impurities	Compressor performance loss	Low pressure compression
4	Clean the air filter. (Perform every 1000 hours of operation)	Filter collapse	Compressor does not compress.	Method of observing pressure gauges, alarms on consoles
5	Clean the air filter. (Perform every 1000 hours of operation)	Filter clogging	Compressor does not compress.	Method of observing pressure gauges, alarms on consoles
6	Cleaning the filters of 40/6 bar reducing stations.	Filters with impurities	Prisons in the intermediate components	Manometers do not show pressure
7	Cleaning the filters of 40/6 bar reducing stations.	Filters with impurities	Filter clogging	Compressor does not compress
8	Cleaning the filters of 40/6 bar reducing stations.	Filters with impurities	Failure of systems dependent on this air circuit.	Stuck on valves, bottles won't load
9	Cleaning the filter between the compressor and the charging bottle.	Impurities in the bottle	Compressed air bottle degradation	Method of observing the outside of the bottle
10	Cleaning the filter between the compressor and the charging bottle.	Impurities in the bottle	Particle injection into downstream circuits	Stuck on valves, bottles won't charge
11	Cleaning the filter between the compressor and the charging bottle.	Impurities in the bottle	Arrest of components in downstream components.	Manometers do not show pressure
12	Check the charging time of the 63lt/40 bar bottle.	Slow bottle loading	Equipment start-up and operation failures	Low pressure, automatic compressor does not stop
13	Oil change	Oil outside normal parameters/contaminated	Air compressor degradation	Compressor takes longer to load compressed air bottles. Lubrication oil analysis.
14	Oil change	Oil outside normal parameters/contaminated	Particle entrainment in the circuit/performance losses	Lubrication oil analysis.
15	Oil change	Oil outside normal parameters/contaminated	Particle entrainment in the circuit/trapping in intermediate components (e.g. valves)	Lubrication oil analysis.

Table 3. Results of FMECA & FMECA-CC

Nr	FMECA	FMECA-CC Without ln	FMECA-CC
1	625	375	6
2	375	4050	8
3	156	94	5
4	156	31	3
5	135	1296	7
6	550	660	6
7	108	1166	7
8	104	1331	7
9	30	432	6
10	56	134	5
11	52	749	7
12	90	216	5
13	162	583	6
14	38	243	5
15	192	2074	8

Observing table nr 3 it is observing that for both FMECA and FMECA-CC the nr 2, and nr 15 are in critical situation so the maintenance must be done.

The nr 3, 5, and 5 to 14 are in semi critical situation, but not accordingly FMECA.

Observing the results, we can observe that the FMECA-CC is more sensitive than FMECA, and it is acceptable, because one aim is to enhance the traditional FMECA performance crossing the fixed maintenance procedure with the condition control data.

So, based on the results and accordingly the defined procedure, actions of maintenance and/or monitoring should be taken and planned accordingly the ship operational plan.

In the present article it is called active maintenance to preventive maintenance which integrated condition-based maintenance, and the risk based the created relations between FMECA and Condition Control.

5 Conclusions and Recommendations

It is believed that risk analysis in dynamic ship maintenance is a crucial area to ensure the safety and efficiency of maritime operations.

This scientific paper explored the complexity of the challenges faced in dynamic ship maintenance and highlights the importance of a rigorous risk analysis approach.

The findings can effectively manage risks associated with ship maintenance improving crew and operational safety but can also result in significant long-term cost savings and consequently more friendly of the environment.

By integrating condition control on FMECA, it may allow enhancement on maintenance management on ships considering an equipment dynamic intervention decision.

FMECA-CC had shown more sensitivity than the traditional FMECA.

The application of risk analysis in dynamic ship maintenance, emphasizes the need for a comprehensive, data-driven, and collaborative approach to effectively mitigate risks and ensure the safety and efficiency of maritime operations.

For future work, explore systems of artificial intelligence applied in online risk analysis and dynamic ship maintenance may be an aim for the effectiveness of FMECA-CC.

Acknowledgments

The authors from UNIDEMI acknowledges the Portuguese Fundação para a Ciência e a Tecnologia (FCT—MCTES) for its financial support via the project UIDB/00667/2020 and UIDP/00667/2020 (UNIDEMI). The authors from UBI acknowledge Fundação para a Ciência e Tecnologia (FCT) and C-MAST (Centre for Mechanical and Aerospace Science and Technologies) for their support in the form of funding, under the project UIDB/00151/2020.

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