An approach to Ship Equipment Maintenance Management

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Abstract. Ships can navigate several months on sea. Maintenance and supply are the base for ship successful navigation and mission. Every type of equipment should have a maintenance plan. If it is a corrective maintenance plan, some risks are inherent. This study pursues a Management Maintenance System considering minimal costs, where the best equipment availability and performance is the objective. For this work, an air compressor was chosen as study case from a ship and considered three study stages. The first stage consisted of the definition of evaluation criteria and its meaningfulness. The data treatment from the first stage can provide enough information to define the second stage's maintenance methodology decision. Also, the decision-making itself based on the process is the third stage. The development of decision-making methodology for maintenance management was based on a Fuzzy method considering a Risk-Based Maintenance on ship equipment.

Keywords: Risk, Naval Maintenance Management, Fuzzy Methodology.

1 Introduction

The developments in maintenance management are in continuous changing due to complex systems and equipment [1]. Fuzzy data is being applied for modelling complex systems [2]. The decision-making processes based on risk are supported by variables that do not admit accurate values. So in this work, is developed a methodology to quantify the" quality" and try to eliminate the decision based on human sense and deductive thinking, where people "infer a conclusion from what they know" [3],[4].

Jamshidi [5], in his work, refers to "The evaluating criteria for Maintenance Strategies Selection (MSS) depend on the organisational goals and objectives and could be decided in consensus with field experts." So before starting the study, the evaluating criteria should be defined [6]. Besides, the strategies and the criteria should be adapted to the needs of the organisation and system.

On the ship's maintenance management, the decision-based in advanced industrial models can be a pillar for decision-making representatives and managers. This paper focuses on naval equipment's. Knowing ship equipment's and systems performance versus condition can be crucial for a decision-making process. This work proposes the approach of decision-making based on a risk-based maintenance (RBM) system. It can "reduce the probability of failure of equipment and the consequences of failure." [7]. For this aim knowing the equipment's lifecycle, the maintenance plan is defined accordingly and to enhance the equipment availability [8].

When a risk-based maintenance system is applied, preferentially, it should be based on a quantitative system [9]. So, this paper presents a methodology to quantify the risk of not pursuing a maintenance action even when needed. The authors believe that applying the Fuzzy models will define the criteria and decision-making process on a Risk-Based Maintenance process implemented on a system or equipment. Therefore, a Fuzzy analysis is proposed in the obtained data. Fig. 1 shows the five Fuzzy used criteria for this study: the monitoring cost, efficiency, failure, safety, and if it is feasible.

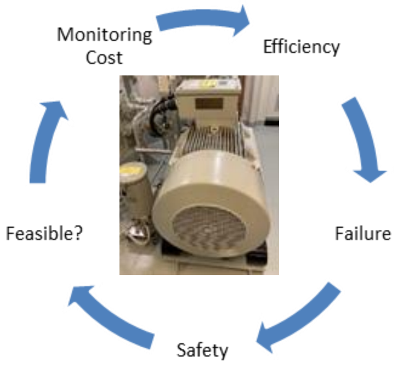

Fig. 1. Fuzzy Criteria defined for the equipment

2 Condition-Based Maintenance in ships

Ships and maritime transports have been the most critical means to take goods from their origin to destiny for more than centuries. Meanwhile, the globalisation and growing market competitiveness have changed, and still change, the way to manage firms. In this logic, the maintenance is a critical variable to reduce management costs, "whose costs account for the most cost of ships machinery maintenance" [10],[11].

Given this situation, it is crucial to establish a maintenance plan according to the data collection and analysis of equipment that should be considered too. There are two types of maintenance in theory: Corrective (CM) and Preventive Maintenance (PM). The second one divides into Systematic Maintenance and condition-based maintenance (referred to as CBM). CBM, according to Telford et al. [12], is "preventive maintenance based on performance and/ or parameter monitoring and the subsequent actions." Lately has been highlighted because of its power to reduce maintenance costs effectively. This strategy recommends that maintenance actions (decisions) should be performed based on the "information collected through condition monitoring process" [13].

CBM may be used in three main methodic steps: data acquisition, data processing and maintenance decision-making [14],[11], and this data is achieved, if possible, by longs periods of monitoring systems. Once it is decided that equipment is going subjected to condition-based maintenance, the first work is to assess its decay status. If there are a set of components is vital to study their decays status, decay degrees, and the decays set direction and evaluate which one has decayed more [10]. With these data, it is profitable to schedule the next maintenance and avoid failures.

According to Hwang et al. [15], CBM has four function modules: diagnostics - that match the asses of equipment decays status and investigate the type of correspondent failures that can occur; prognostics - that follows the identification of a failure module type and then tell the Remaining Useful Life (RUL); maintenance - using diagnostics and prognostics results from it is possible to maintenance equipment and schedule it; last but not least, configuration managements function when are design standards and requirements of the equipment to prevail constant and consistent at all times.

Decays data can either be generated by a real data validated simulator, and based on that data, CBM is an important and proactive decision-making tool [16]. Thus, this strategy has the advantage of preceding warnings of stop failures and increased precision in failure prognostic. On the other hand, the main disadvantage is an investment in installing and controlling the monitoring equipment and on stipulating the decision-making systems [11],[13],[17].

CBM has been studied in the most variety of manufacturing firms, equipment or set of equipment during the past years. This paper will study if CBM is appropriate to manage and decide maintenance plans in ships, as has already been done [10],[12],[15].

3 Fuzzy Methodology in Maintenance

Ahmad & Kamaruddin [13] refer that "The main aim of diagnosis is to provide early warning signs to engineers while the monitored equipment is operating".

Maintenance plans are frequently designed by studying the maintenance tasks and then prioritisation those. There are a lot of logic methods to follow, and Fuzzy Logic is one of them. Fuzzy models have been highlighted "for measuring uncertainty in productions control fields", such as maintenance concerns [18][19][20].

Fuzzy modelling, as a many-valued logic, allows the utilisation of imprecise information. These models can achieve solutions with uncertain input data that standard mathematical models cannot [19]. A mathematical model is quantitative, so it may show several challenges in the implementations due to systems complexity, which is highly dimensional, nonlinearities and parametric uncertainties. In contrast, qualitative approaches receive an analysis of historical data to develop a solution [21]. Fuzzy theory's main advantage is that "deals with subjective, incomplete or unreliable knowledge bases" by having inputs linguistic variables, thus is the most appropriate to qualitative approaches [22].

Once is decided that fuzzy logic will define maintenance plans, it is crucial specify which kind of logic is appropriated: Early Warning Systems (EWS) [11], Real-time information (RTI) [18], Network Formulation (NT) [21], Multi-Criteria Decision-Making (MCDM) [23], Supporting Risk Matrix Prioritisation (SRMP) [24], and others.

This paper will use the Fuzzy Logic considering Risk-Based Maintenance (referred to as RBM) as the maintenance decision system. RBM is a crucial tool to lead failure mitigation by studying accidents probability and respective costs consequences. It also has a critical role in controlling the validity of safety investments, managing potential accidents instead of performance maintenance plans [25].

RBM aims to schedule maintenance with dynamism taking the risk of failure as a start point. First, risk should be calculated, and then maintenance is scheduled [12], [22]. Risk Assessment can be approached by Risk Index or Probability. Then, Maintenance Schedule Technique by Expert Judgement or Optimisation. Another approach is to "assess the consequences of action and prioritise maintenance tasks based on the risk of potential failures" [20].

Selecting the criteria (or multiple criteria) is possible to obtain priority weigh based on Fuzzy interval ranges. All interactions between criteria and maintenance plan alternatives will be considered uncertainty, which provides better results than conventional decision-making methods [26].

4 Methodology development

The ship in the study is maintained through the Maintenance Management System – MMS - that the aim is to reach the balance between preventive and corrective maintenance. The goal is to monitor equipment performance. Three methodologic steps usually compose MMS (see Fig. 2): 1 - Planning; 2 - Execution; 3 - Information Treatment. Maintenance planning should consider the specifications and needs to proceed with maintenance along time. Execution is the concretisation, monitoring and due dates control of maintenance plan and risk analysis. It can be organised by sequence: first, the need for maintenance is given; second, manufacturer representatives or shipyard resources are made available; next, the required spare parts are made available; for last, the execution or not itself is coordinated. Information Treatment is started by collecting maintenance data, then analysing and treating and finally distributing this information.

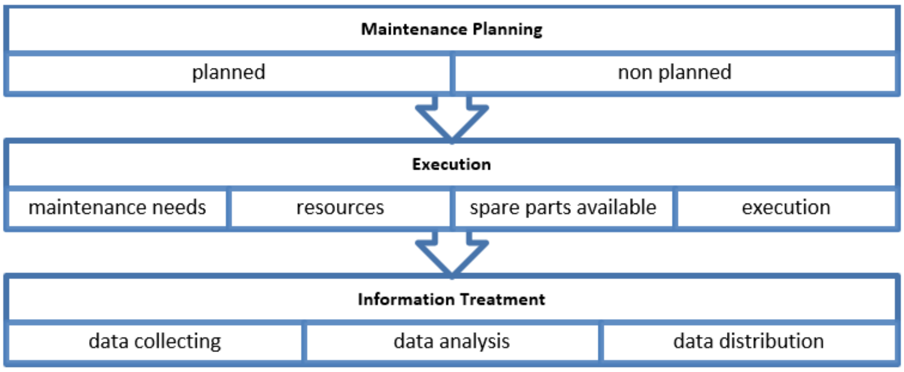

Fig. 2. Methodology scheme

Although the organisation has its own maintenance plan, it also follows the Portuguese normative [27]. The maintenance system plan is split into preventive maintenance and corrective maintenance in the organisation, Fig. 3. In this study, the principal type of applied maintenance is corrective, but the conditioned maintenance techniques are considered to avoid total failure.

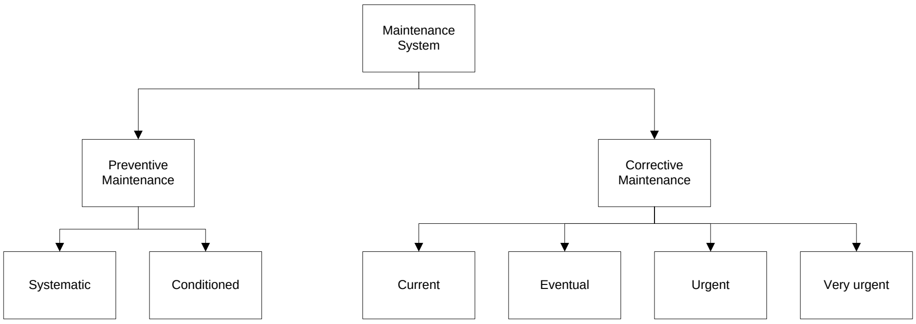

Fig. 3. Maintenance in the organisation

When it comes to technical means, the ship, which it was used for study, has three levels of maintenance: First Level - is when maintenance is performed by replacement of components and tools on board. In other words, when it is possible to develop the maintenance plan inside the ship with its resources (personnel and material) safely and effectively. Second Level - is when maintenance can be performed onboard and/ or on land because ship resources and capacity are not self-sufficient to execute it. Third Level - is when equipment or components should be maintained on land because their maintenance plan and the current situation is complex, and the space on board and its resources do not allow safe maintenance. This Third Level is executed by shipyard or by representatives of official manufacturers [28].

The Failure criteria, it was defined as the failures based on the MTBF (Mean Time to Failure). The Safety criteria were based on the personnel injuries, the equipment safety and any environmental impact. For the Efficiency criteria, it was analysed the efficiency of the personnel and material performance. For Feasible maintenance, it was considered the available employees and tools. The criteria Cost of Monitoring included personnel education, portable equipment, fixed equipment, and software costs. All the five criteria compete with a data processor, which provided the results to maintenance decision.

The Fuzzy Logic Control was applied to analyse corrective maintenance risk and the implication to do or not in the universe criteria, as showed in Fig. 4, considering other risk-based maintenance systems used to compressors [10].

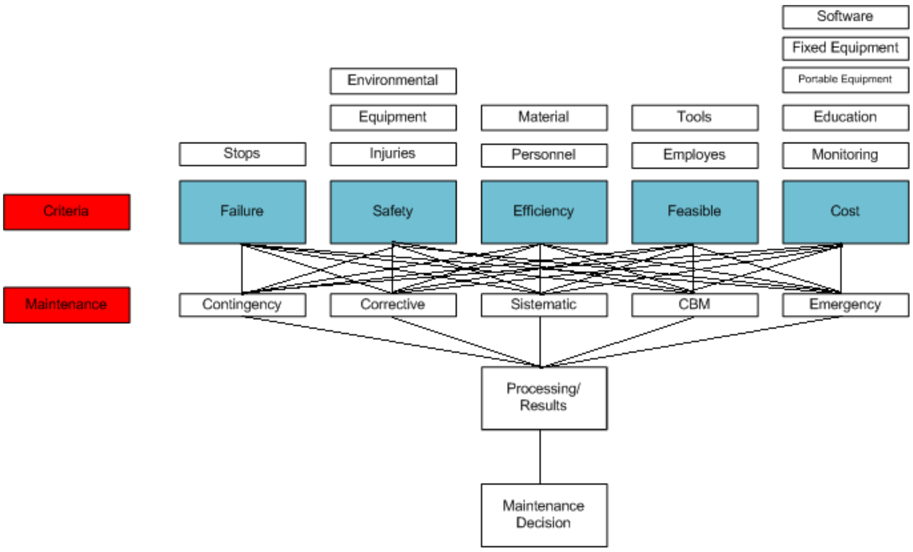

Fig. 4. Fuzzy on Risk Analysis

5 Case Study

An air compressor onboard it is vital for other systems functioning. Engines and power generators can depend on this for a start and even for some operations during the running. The air-compressor understudy is pursuing a bath life cycle, and it is in the middle of the lifecycle. It is believed that a risk-based maintenance system support by Fuzzy methodology can be applied [29]. The present research uses an air compressor from a ship to validate the developed system. According to the manufacturer manual, the air compressor maintenance must be based on time interval predetermined and carried out under an established time schedule or set times of use – Schedule Maintenance. An example of this schedule is Fig. 5.

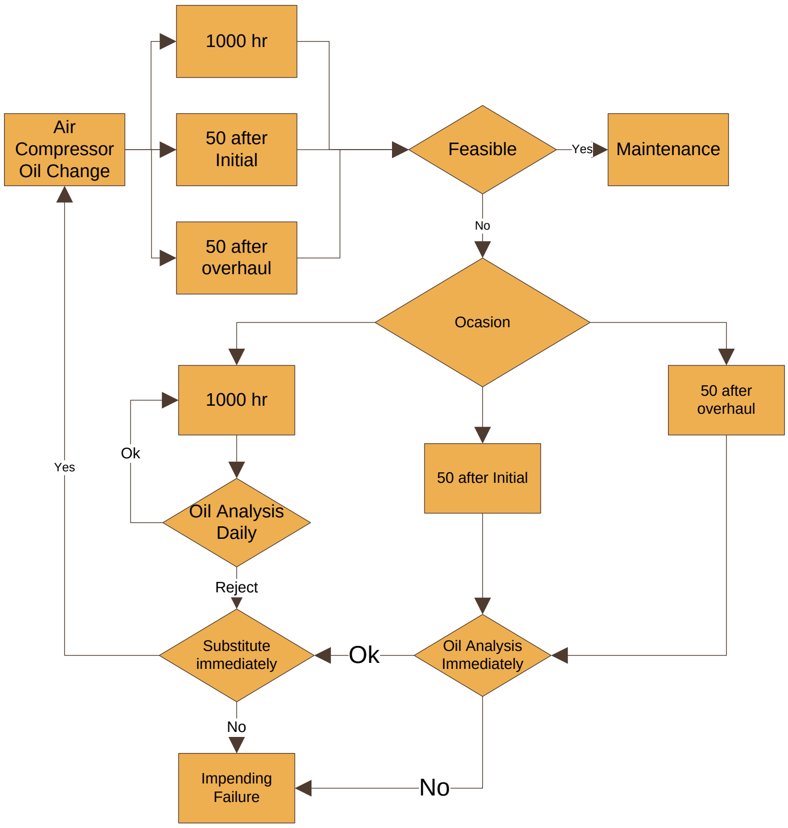

Fig. 5. Air compressor maintenance for 50hr and 1000hr [30]

An example of periodic checks on the compressor is in Fig. 6. These checks correspond to periodic maintenance defined by the manufacturer.

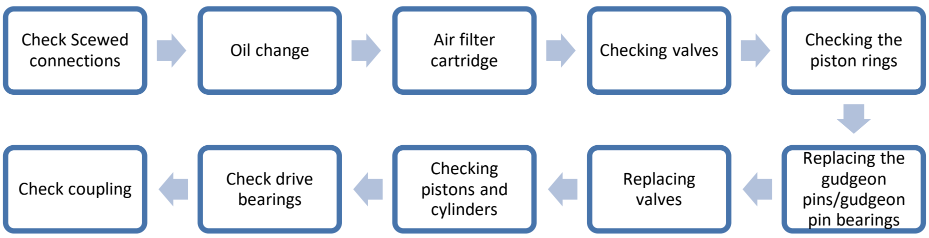

Fig. 6. Air Compressor Checks [30]

The idea of the developed system is, considering the air compressor maintenance defined by the manufacturer (phase 1 of the defined methodology), as shown in Fig. 7, to quantify the risk of not doing planned maintenance. It will be considered that: if the planned maintenance of 1000hr or more hours is not made, some simple maintenance will be done (for example, oil and filters change), and the risk of not doing it must be quantified. It was considered 10% of additional risk for each undoing maintenance, only the risk of the oil and filter unchanging will be exposed; this is first-level maintenance carried out by the ship. It was considered the activity *per si*, what can happen and the impact. To obtain the results and quantify, the probability, impact, and exposure were applied.

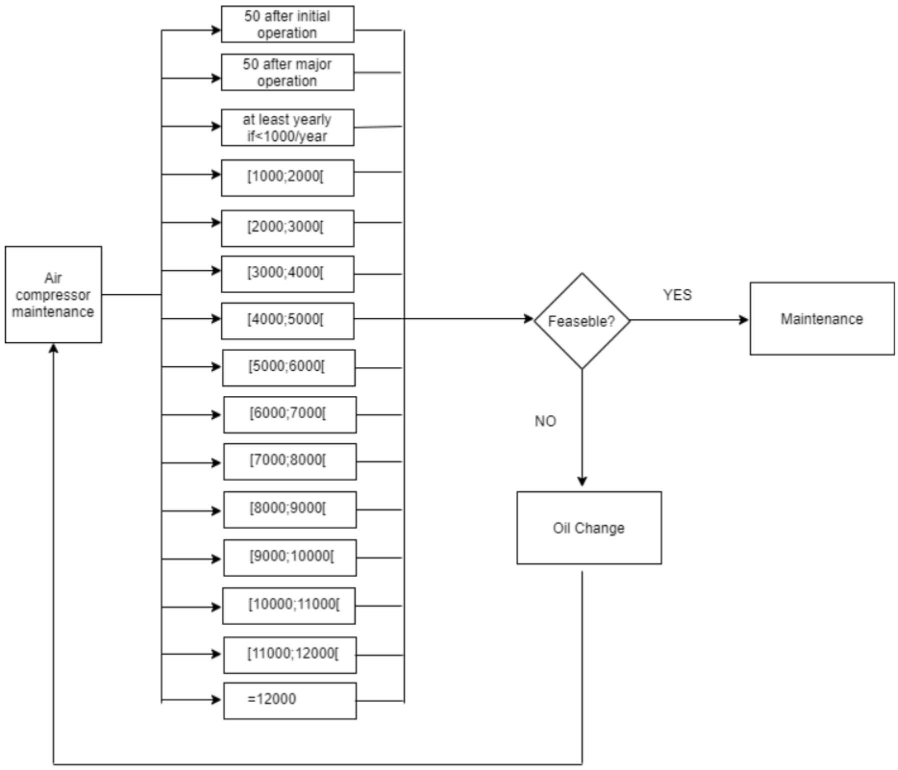

Fig. 7. Air Compressor Maintenance according to the manufacturer manual [30]

The considering maintenance cannot be feasible for the five defined criteria (see Fig. 4). The fuzzy methodology is expressed in phase 2 of the described methodology of the execution.

With undoing the maintenance, but with good oil analysis and functioning parameters, the results were positives so that the air compressor can function normally. With some loss of oil properties, it can work with some time limit. With the total loss of oil properties and the parameters out of control, the compressor should be stopped immediately, with the risk of the catastrophic anomaly. Corresponds to phase three of the defined methodology.

So, if the decision is not to proceed to maintenance, the air compressor must continue with Condition Based Maintenance (CBM), considering oil analysis, parameters check, and vibration measures. If the performance of the compressor decreases, these procedures should be made more often.

6 CONCLUSIONS

For this work, three-stages of risk-based maintenance analysis were considered. At first, the criteria were defined. Then, the way of criteria interacts and its values with software or personnel evaluation were established. In the third stage, as a result, the maintenance plan was defined.
The studied air compressor is selected equipment from a ship, and other equipment types depend on it, so the risk of undoing some maintenance can conduce to a failure. Some condition-based maintenance techniques should be used to avoid an unexpected failure, and the risk of unfulfilled maintenance is calculated.

The three-stage defined methodology can be applied in equipment monitoring.

For risk assessment, the risk should be identified, analysed, and quantified.

It is also concluded that applying the Fuzzy logic in a Maintenance System Plan is viable and can support decision making. Also, the RBM is workable for the organisation, can decrease the maintenance cost, and increase the reliability in systems.

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