Application of Fuzzy Methodologies in Navy Systems Maintenance

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Abstract. In an environment of scarce resources, enhancing the ships performance by minimizing equipment intervention actions and maintaining safety standards is an actual challenge. Ships, not yet autonomous, are maritime means that transport personnel and systems. Their good condition is a permit for the safety of personnel and material, avoiding damage to the ship itself and possible occurrences of pollution at sea or damage to other systems - seafarers and people outside the east. Companies, organizations, and the scientific community with an interest in ship maintenance management have been developing advanced systems for monitoring ship equipment; to prevent malfunctions and have on-site knowledge of the state of the equipment. These systems use condition control techniques and data processing through algorithms, statistical systems, and other methodologies. The methodology that will be developed and applied in this investigation is Fuzzy. The equipment chosen for the case study is a fire pump from an ocean patrol vessel, which is vital equipment on board, and which is part of the equipment selected by the Technical Management of the Organization understudy to monitor operating hours and operational status.

Keywords: Fuzzy, Maintenance, Risk, Ship, Equipment.

1 Introduction

The importance of maintenance as a production support activity has become unquestionable due to its vast contribution in terms of operability and improvement of physical assets.

In this context, the concept of maintenance management was developed, defined by *Instituto Português da Qualidade* (IPQ) [1] as “all management activities that determine the objectives, strategy and responsibilities regarding maintenance and that implement them by various means such as such as planning, controlling and supervising maintenance and improving methods in the organization, including economic aspects.”

Maintenance planning concerns all activities related to developing of a regularly scheduled work program to ensure the satisfactory operation of the equipment and avoid serious problems [2].

On the other hand, maintenance control and supervision are related to the various aspects that must be monitored to ensure the correct implementation of maintenance management [3]. According to Morvay & Gvozdenac [4], any management system comprises an organizational structure supported by three main aspects: procedures, people, and technology to control and optimize the use of resources and ensure the fulfilment of the company's objectives.

An information system can support the maintenance planning, execution processes to ensure the management of work lists, inventory, procedures and technical specifications, scheduling, and resources management. It can also conduct to transmission of interventions requests, monitoring, and spare parts reporting and cost control management. In this logic, the role of technology appears as a need for an information system closely connected to all relevant company assets and as a valuable tool for operators to ensure more reliable interventions [5].

However, no management is easy, and the maintenance management of maritime assets is complex due to the uncertainties and constraints involved, such as weather conditions [6].

If objectives like: reducing the number of accidents, developing a flexible and multifaceted organization, improving production efficiency and, for example, creating a more accessible and perceptible system for all the people involved; are achieved, then it can be said that the fundamental reasons for maintenance management are also being fulfilled, maximizing profit and offering a competitive advantage to the organization. This varied set of arguments has led to the choice and implementation of the “ideal model” no longer just a vague thought to become a recurring topic of research and a fundamental issue to achieve the effectiveness and efficiency of maintenance management [7].

In the context of maintenance management, with the objective of minimize unexpected breakdowns, the Fuzzy methodology was chosen to develop a decision support model in the context of the maintenance of a ship fire pump.

2 The Fuzzy Methodology in Maintenance

Fuzzy logic came to give some answers regarding data that are neither false nor entirely true. This logic can develop a system for decision making based on inputs of linguistic variables and, therefore, often vague and subjective from a mathematical point of view [9]. This methodology is used to express the absence of a clear boundary between sets of information [10]. According to Ierace & Cavalieri [9], this technique is suitable for maintenance since the authors consider that, for the most part, the general objectives of maintenance are intangible and depend on the worker's experience. However, according to the same authors, this method is sometimes too subjective, making it difficult to assess the importance of each objective, and the ability of each maintenance policy to achieve them.

2.1 Fuzzy Process

This methodology is suitable for working with imprecise human reasoning because it considers experience and knowledge. It also provides a mathematical framework to model the uncertainty of human cognitive processes that can be controlled by a computer [11].

To accomplish the Fuzzy methodology appliance, it was considered various steps and phases inherent to Fuzzy Logic process [12]. The phases of this study and the Fuzzy steps are identified in Fig. 1 [12][13].

Fuzzification is the process that converts input data into fuzzy values using membership functions. At this stage, the degrees of belonging of the elements are determined. In addition, as an essential process step, the specialist's contribution to the phenomenon under study that is intended to be modelled is usually justified [14]. On the other hand, the inference is the process that aims to enable a system action by evaluating the compatibility of the inputs with the conditions stipulated by the rule base. The number of fuzzy output sets must equal the number of stipulated rules [15].

Four types of inference methods are commonly discussed in the literature: the Mamdani model and Larsen's model. In these models the antecedent and consequent are fuzzy propositions. The Tsukamoto model differs from previous models. The consequent is represented by a monotonic membership function. The Takagi-Sugeno model in which the difference lies in the consequent being a polynomial function [16]. It should be noted that the four methods differ only in the consequent.

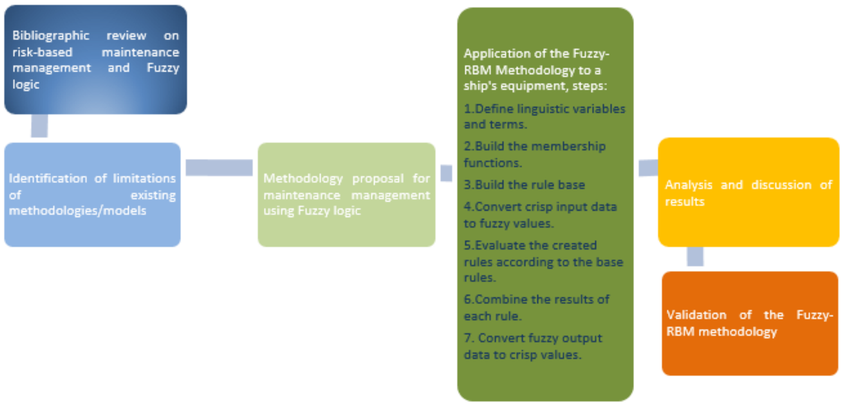

Fig. 1. Phases of Study and steps in a Fuzzy System
Source: adapted from [7] [12][13]

Defuzzification is the step in which the system's output values are calculated based on the inference process and according to the belonging functions of the linguistic variables. The number of rules stipulates the number of outputs; if, for example, five rules are determined, then there will be five output values. However, there can only be a single final response value determined on a case-by-case basis since it has to be the one that best reproduces the region obtained through the output values [17]. There are several defuzzification methods, such as the Center of Gravity (COG), Center of Area (COA), and Mean of Maximums (MOM), among others. Only because it is the most used and referred by various authors, in the present investigation, the authors chose to use the COG.

COG finds the point where a vertical line cuts the fuzzy set into two equal parts. The method finds a centre of gravity of a set A in an interval ab. Mathematically, the COG can be calculated in at least two ways; the first, presented in equation 1 [13].

$$COG = \frac{\int_a^b \mu_A(x)xdx}{\int_a^b \mu_A(x)xdx} \qquad (1)$$

The second way is presented in equation 2; the COG is calculated through an estimate obtained through a sample of points [11].

$$COG = \frac{\sum_{x=a}^{b} \mu_A(x)x}{\sum_{x=a}^{b} \mu_A(x)} \qquad (2)$$

In equations 1 and 2 the symbols meaning are:
a and *b* – represent an ab interval.

x- it's the variable;
μ_A- degree of membership in relation to the fuzzy set A.

Following the example of age, the linguistic variable is age, which can take linguistic terms such as young, middle-aged, or old, this phenomenon happens because usually, human beings express themselves in this way, in words instead of numbers [18]. Therefore, these linguistic terms can be described through fuzzy sets, which in turn are represented through membership functions that will be presented in the Case Study of this article.

2.2 Conjuntos Fuzzy

A fuzzy set A, belonging to a universe U, is defined through a membership function:

$$\mu_A\,(x) : U \rightarrow [0,1] \tag{3}$$

This membership function represents a fuzzy set through a set of ordered pairs given by:

$$A = \{(x, \mu_A\,(x)) \mid x \in U\} \tag{4}$$

In which there is only one match, a real number from the range [0,1], for each element x. The closer the value of μ_A is to 1, the greater the possibility that the element x belongs to the set A. This degree of belonging of the elements allows the occurrence of gradual transitions between true and false.

The gradual transition is given by:

$$\mu_A\,(x) : x \rightarrow [0,1], \begin{cases} \mu_A\,(x) = 0 \\ 0 < \mu_A\,(x) < 1 \\ \mu_A\,(x) = 1 \end{cases} \tag{5}$$

The membership functions use numerically translated linguistic terms that allow obtaining output values, in the fuzzification and defuzzification stages, respectively. These functions can be of different types such as rectangular, triangular, trapezoidal and others, the last two being the most frequent in the literature [14]. Triangular and trapezoidal membership functions can be described through the following equations and respectively [19]:

$$\mu_A = \begin{cases} 0, & se\ x < x_1 \\ \frac{x - x_1}{x_2 - x_1}, & se\ x_1 < x \le x_2 \\ \frac{x_3 - x}{x_3 - x_2}, & se\ x_2 < x \le x_3 \\ 0, & se\ x > x_3 \end{cases} \tag{5}$$

$$\mu_A = \begin{cases} 0, & se\ x < x_1 \\ \frac{x - x_1}{x_2 - x_1}, & se\ x_1 < x \le x_2 \\ 1, & se\ x_2 < x \le x_3 \\ \frac{x_3 - x}{x_3 - x_2}, & se\ x_3 < x \le x_4 \\ 0, & se\ x > x_4 \end{cases} \tag{6}$$

In the current state of the art, it is possible to find several examples of complex problems in which this logic has contributed to their understanding: as Meng Tay & Peng Lim [20] in its application in the manufacture of semiconductors, and Chung & Kim [21] in the wastewater prioritization.

The application of Fuzzy Logic has advantages and disadvantages. The advantages are: improves the handling of inaccurate data; facilitates the process of specifying the system's rules; is more intuitive due to the use of words instead of numbers; facilitates the resolution of complex problems; provides faster development of system prototypes [22]. Moreover, the disadvantages: it makes it difficult to analyze aspects such as optimization; the specialist's experience and knowledge limit the accuracy of the fuzzy system; system is influenced by all its parameters, such as the method chosen for fuzzification, or the number of rules [23].

3 Methodology

The proposed methodology for implementing Fuzzy logic assessing of the risk of failure of a fire pump on board a ship will contribute to determining the type of maintenance best suited to the reality in the organization and in the maintenance planning of assets. Therefore, the integration of this methodology within the scope of risk-based maintenance will then be demonstrated. The first step for implementing of Fuzzy logic will be the choice of equipment to implement the methodology. In Fig. 2 is presented the Fuzzy methodology for a ship' equipment.

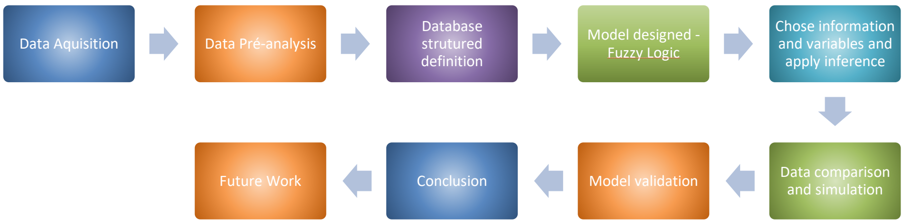

Fig. 2. Fuzzy methodology for a ship's equipment

4 Case Study – Fire Electro Pump

In this study the Fuzzy methodology is applied to the electro pump system (Fig. 3).

Fig. 3. Fire Electro pump (Original photo from the corresponding author)

To build the Fuzzy methodology with information about a fire electric pump is essential to mention that the Ocean Patrol Vessel has several Fire Electric Pumps. Electric fire pumps are selected equipment, which means that the number of operating hours is counted for their maintenance management and that it is considered a vital piece of equipment in the ship's operation. The general characteristics of the electric fire pump shown in Fig. 4 are 100 m3/h of Capacity; Head, 99.6 m; 2950 l/min of Speed; 44.7 kW of Power Absorbed and 55 kW of Electric motor power. [24]

The basic preventive maintenance procedures for the fire pump are visual inspection, vibration measure, sealing organ substitution, pump external preservation, gauge calibration and measure of insulation resistance.

4.1 Fuzzy Parameterization

To perform the parameterization in the application of the Fuzzy system various simulation of criteria and its limits was taken. Finally, the frequency (F) of the failure was considered from remote to very frequent (4 to <15), the operational impact (OI) from low to extremely high (0 to <5), safety and environment impact (SI) from low to the high (1 to <5), low to high maintenance cost (MC) (1 to <5). The consequence (C) is a result of the sum of OI, SI and MC that contribute equitably. These criteria and limits were the ones that showed to be more applicable for the equipment performance. This subject is not more detailed because of the conference article dimension limitation.

Table 1 are presented the inference rules, and in Table 2 the risk level classification.

Table 1. Inference rules[1]

Rule Nr	Rule	Rule Nr	Rule
1	If (**F** is **MF**) and (**C** is **Ba**) then (**R** is **NC**)	11	If (**F** is **PF**) and (**C** is **Ba**) then (**R** is **NC**)
2	If (**F** is **MF**) and (**C** is **Mo**) then (**R** is **PC**)	12	If (**F** is **PF**) and (**C** is **Mo**) then (**R** is **NC**)
3	If (**F** is **MF**) and (**C** is **A**) then (**R** is S**C**)	13	If (**F** is **PF**) and (**C** is **A**) then (**R** is **PC**)
4	If (**F** is **MF**) and (**C** is **MA**) then (**R** is **C**)	14	If (**F** is **PF**) and (**C** is **MA**) then (**R** is P**C**)
5	If (**F** is **MF**) and (**C** is **EA**) then (**R** is **MC**)	15	If (**F** is **PF**) and (**C** is **EA**) then (**R** is S**C**)
6	If (**F** is **Fr**) and (**C** is **Ba**) then (**R** is **NC**)	16	If (**F** is **Re**) and (**C** is **Ba**) then (**R** is **NC**)
7	If (**F** is **Fr**) and (**C** is **Mo**) then (**R** is **PC**)	17	If (**F** is **Re**) and (**C** is **Mo**) then (**R** is **NC**)
8	If (**F** is **Fr**) and (**C** is **A**) then (**R** is S**C**)	18	If (**F** is **Re**) and (**C** is **A**) then (**R** is **NC**)
9	If (**F** is **Fr**) and (**C** is **MA**) then (**R** is **C**)	19	If (**F** is **Re**) and (**C** is **Ma**) then (**R** is **NC**)
10	If (**F** is **Fr**) and (**C** is **EA**) then (**R** is **C**)	20	If (**F** is **Re**) and (**C** is **Ea**) then (**R** is P**C**)

Table 2. Risk level classification

Risk level	Value
Very Critical	R > 200
Critical	150 < R ≤ 200
Semi-critical	100 < R ≤ 150
Less Critical	50 < R ≤ 100
Not Critical	R ≤ 50

For the defined attributes and the considered situations, the risk calculation is presented in Table 3. And it was based, after various simulation, in equation nr 7:

$$R = FxC \tag{7}$$

[1] F-Frequency; C-Consequence; R-Risk; MF-High Frequency; Fr-Frequent; PF-Infrequent; Re-Remote; Ba-Low; Mo-Moderate; A- High; MA-Very High; EA-Extremley High; NC- Not Critical; PC- Little Critical; SC-Semi-critical; C-Critical; MC-Very Critical.

Table 3. Risk calculus result

Risk	TL R
0	Not Critical
12	Not Critical
30	Not Critical
48	Not Critical
128	Semi-Critical
36	Not Critical
40	Not Critical
110	Semi-Critical
120	Semi-Critical
182	Critical
200	Critical
150	Semi-Critical

The membership functions used to convert the frequency input values into linguistic terms, and the linguistic terms into output values are translated in Fig. 4.

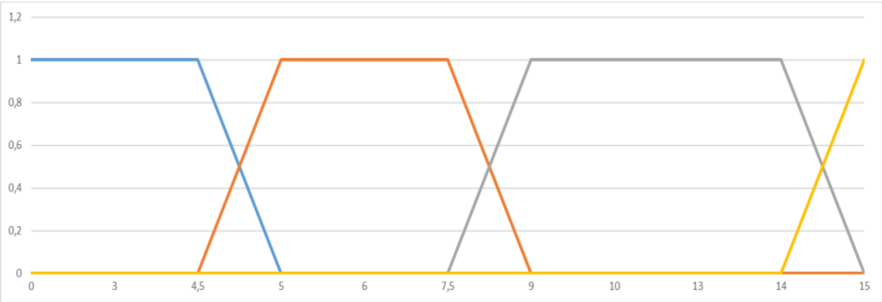

Fig. 4. Trapezoidal membership function

The attributes levels that served as the basis for the developed methodology were defined based on the maritime maintenance expertise, and after various scenarios, simulation and attribution of various intervals values on considered the criteria.

Based on the developed inference in Fuzzy Logic, in the study of the ship´s fire pump, the obtained results was in a range between non-critical and critical.

There was no overlapping of results in the trapezoidal membership function, which translates into a sufficiently adjusted model. Although the obtained results, and if this methodology is applied, we suggest the need to observe equipment operation under the present rules and maybe adjust it if necessary.

5 Conclusion

The Fuzzy methodology allows the measurement of human cognitive records, for which some criteria must be considered, and these must have several levels to be able to obtain a quantification of results through an algorithm.

Fuzzy logic converts text input data into fuzzy values using membership functions.

The result of the algorithm can be a risk level that allows the perception of the urgency of performing maintenance on equipment.

The Fuzzy methodology was applied to a ship's fire pump to serve as a decision support system for its maintenance.

In this decision support system, considering the methodology and method, the trapezoidal membership function did not result in overlapping results. It seems to be partially validated but must be subjected to a practical application under supervision of those responsible for implementing the system.

Applying Fuzzy Logic in ship equipment may help develop a decision support system in maintenance management of Portuguese Navy ships.

This methodology should be adapted and tested on other equipment's.

Acknowledgements

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