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Maintenance Strategy Selection Using Fuzzy Delphi Method in Royal Malaysian Air Force

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ABSTRACT

The proper maintenance strategy is significant in extending assets and equipment, thus saving maintenance within an organization. Currently, there are three types of maintenance strategies implemented in the Royal Malaysian Air Force (RMAF), namely Reactive Maintenance (RM), Preventive Maintenance (PM), and Condition Based Maintenance (CBM). Due to the constraints in terms of maintenance costs by RMAF, choosing the right maintenance strategy is important to ensure that the maintenance provision can be optimized. In this research study, the Fuzzy Delphi Method has been used as a tool in determining the most effective maintenance strategies to be adopted by the RMAF. The output of agreement and opinion from experts in the related field has been used to select the appropriate maintenance strategy. In choosing this maintenance strategy, goals are set first in line with RMAF maintenance's objectives. The specified maintenance goals are as follows; low maintenance cost, reducing the chance of a breakdown, safety, feasibility on the acceptance by labor, and response time starting from failure. Later, the result showed that the fuzzy score for RM, PM, and CBM was 0.747, 0.789, and 0.767, respectively. The highest fuzzy score showed the most accepted method chosen by the expert. Based on the result

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and maintenance goals that have been outlined, experts have agreed to choose PM as a maintenance method that should be given priority to be implemented in RMAF compared to other maintenance methods due to the highest fuzzy score.

Keywords: Condition-based maintenance (CBM), fuzzy Delphi method (FDM), preventive maintenance (PM), reactive maintenance (RM)

INTRODUCTION

A maintenance strategy system is essential and important for an organization, especially in the Royal Malaysia Air Force (RMAF). The military equipment includes building complex, radar equipment, runaway, and many more assets to be preserved and maintained. All these assets should be in the best condition as this is considered a high priority for the safety of the state and country's aerospace. Therefore, the wrong selection of maintenance strategy can directly impact the maintenance costs in an organization and national security.

In line with that, the sustainable approach for maintenance strategy is vital as a high investment need to be spent for long-term developments and survival of engineering systems. A major part of all engineering and production plants' total operating expenditures comes from maintenance costs (Nquyen et al., 2014; Kumar et al., 2018). Thus, selecting the correct maintenance strategy method for an organization is crucial. It can be observed that an approximate amount of 75 to 80% of expenses will be spent for the use and maintenance stage for a building with a life span of 50 years (Madureira et al., 2017). Therefore, the reduction of cost on building and equipment can be attained by implementing an appropriate maintenance strategy in an organization.

Several effective methods have been emphasized in maintenance culture to benefit the user—this benefit is related to the operational saving cost, reduction of downtime, safety, and equipment sustainability. Many physical engineering failures can be traced through machine performance degradation assessment (Tran et al., 2012; B. Liu et al., 2017). The parameters used to monitor equipment conditions were vibration, sound, and temperature (B. Liu et al., 2017). The research on reliability engineering, problem, and functions related to maintenance strategy has been extensively studied (Nguyen et al., 2014; Kumar et al., 2018). Maintenance actions are commonly arranged into three categories. They are Corrective Maintenance (CM), Preventive Maintenance (PM), and Condition Based Maintenance (CBM) (Wang & Xia, 2015; Kumar et al., 2018). It is denoted that CM includes action to repair or replace parts if the system fails. However, in PM, necessary work or measures are taken to prevent failures or items under a particular condition.

In contrast, CBM refers to detecting failure symptoms produced by equipment through temperature, vibration, and sound. For the scope of reliability engineering, when the system or item shows a problem or failure, CM actions are implemented regardless of PM actions. In contrast, measures will be executed even though the system is fully functioning. In contrast, CBM actions are established anytime there is a need for implementation (Kumar et al., 2018).

All this maintenance strategy aims to have recovery on the system in a better-quantified level through the organized or systematic finding of the condition, replacing a damaged component, amendment for minor defects, continuous observation, and several other actions that can enhance the life span of the system (Dong & Frangopol, 2015; Carnero and Gómez, 2017).

Although CM can be categorized as a type of energy saving in the maintenance method, this method is not cost-efficient (Yu et al., 2019). Moreover, a comprehensive PM action schedule is important to improve system reliability, reduce system downtime, and improve system life span (Fraser, 2014). However, PM actions are not employed in most residential offices and school buildings. Consequently, to cut the number of failures in the systems during operation, CM actions will be implemented to focus on the energy effectiveness of scheduling maintenance (Wang & Xia, 2015).

Many organizations pursue different roles and functions, determining the best concept of maintenance strategy. Therefore, the goal of an organization plays a critical factor in selecting the maintenance strategy to be employed. In getting the proper maintenance strategy to be implemented in an organization, securing consensus from the experts or experienced personnel is one alternative that can be used (Zavadskas et al., 2017). This panel of experts can become an important key in selecting a good decision making based on the maintenance method considered. Thus, incorporating an effective strategy implemented would result in comprehensive judgment among the expert. It later will be contributed to the fairness and balance in decision making with the important element that is embedded along such as identifying and analyzing several specific criteria's (Y. T. Liu et al., 2017; Mitrofani et al., 2020).

Later, it is also essential to integrate the expert's knowledge and experiences in different fields to make suitable judgments. Moreover, this method is frequently used due to the expanding complication in management (Y. T. Liu et al., 2017; Mitrofani et al., 2020). The leading key players consist of project managers and facilities managers as the team of experts. Hence, their existence is the critical aspect for solution models of problem-solving.

An efficient unit of the decision model is a must in collecting a fair judgment from the experiences of the expert (Zavadskas et al., 2017). Sometimes, there will be an unclear path; thus, selecting a management strategy becomes difficult (Jafari et al., 2008; Carnero & Gómez, 2017). However, the experts must characterize and analyze the conditions based on values and rates according to the maintenance processes regarding their knowledge and experience. The action taken for the best maintenance strategy is established by operating and preserving the facilities in good condition. Furthermore, it supports the long-term operating period by optimizing the state function of the infrastructures (Kim et al., 2016).

In time, fuzzy numerical values have been adopted in real-life situations expressing the different stakeholders' opinions and views (Baruah & Kakati, 2020). The appropriate methods can be justified to integrate various information from a group of experts on making a rational decision more comprehensively (Zavadskas et al., 2017). The most crucial step in any decision-making process is accurately approximate the data set. Several studies have introduced a fuzzy concept to solve this problem (Islam et al., 2017; Wang et al., 2020). Some of the approaches using the fuzzy Delphi method had been proposed to evaluate the maintenance strategies (Islam et al., 2017; Zavadskas et al., 2017).

Triangular Fuzzy Number (TFN) has been implemented to generate an uncertainty model in performing the selection process. There was also research on fuzzy linguistic approach in identifying the most suitable maintenance strategy between RM, CM, and CBM (Mechaefske, 2003; Islam et al., 2017). In the approach, the organization firstly forms a group of experts to discuss related maintenance goals, do interviews with employees and managers, highlight the significance of every target, and evaluate the capability of every maintenance strategy in fulfilling the goal of maintenance, respectively. Later, the optimum maintenance strategy will be selected using some related equations in the fuzzy environment. The constraints of deterministic linguistic variables comprised with opinion's baseline with a diversity of opinions become a limitation on the research (Mechaefske, 2003; Islam et al., 2017).

Moreover, competent decision-making can portray the reliable maintenance strategy best practices even in unpredictable circumstances (Jafari et al., 2008; Yu et al., 2019). The variety of maintenance criteria, goals within an organization's role and function, authorities' rules, and regulations affect the selection process. This situation makes the selection process more complex to handle. Consequently, the appropriate tool in decision-making should be implemented (Zavadskas et al., 2017). Another important role in management is choosing the right decisions concerning the several key components. It is crucial to increase the building's overall performance, including operational, quality, and cost, as it is interrelated as facilities' management and the operational process significantly impact the cost, safety, and health of such an organization (Ganisen et al., 2015). The most present facilities management system mainly emphasized collecting data and utilizing information learned from previous decision-making experience. Sometimes, the decision made cannot be implemented in the current situation, and the result of the decision was not comprehensive. Several kinds of data and expertise's involvement needed to be assimilated to assess facility management services.

The facility management team and several building constructors need to integrate with information regarding checklists, work orders, maintenance records, site inspection, interviews, knock-on effects of failures with causes, and many more (Fraser, 2014). Failing to secure information with incorrect interpretation of the applicable data within the time frame given will result in unprofitable choices. Later, it will be contributed to the unnecessary additional costs. Therefore, this research comprised the following objectives:

1. To determine the relevant criteria and assess the alternatives approach in the maintenance strategy system.
2. To evaluate the process on numerical values in determining the rank of each alternative given.
3. To select the most effective building maintenance strategies in the Royal Malaysian Air Force (RMAF).

In obtaining the objectives, this paper focused on evaluating decision-making by selecting the best maintenance strategy to be implemented in the Royal Malaysian Air Force (RMAF). Hence, an appropriate tool of the Fuzzy Delphi method has been executed in decision-making to interpret data and get consensus from the expert. Thus, it will then choose a very effective maintenance strategy regarding maintenance costs. The collection of an incompetent maintenance strategy will affect the direct maintenance expenditures in the organization, particularly in the RMAF. This factor constitutes a major part of all equipment, manufacturing, and production plants (Rasmekomen & Parlikad, 2016). In line with that, a suitable maintenance strategy employed in the system will then reduce the operation cost in the organization (Jafari et al., 2008; Hu et al., 2021). Moreover, the study results later can be applied by other military services such as the Royal Malaysian Navy (RMN) and the Royal Malaysian Army (RMA). These two services generally use the same maintenance method as the Royal Malaysian Air Force (RMAF).

LITERATURE REVIEWS

The term of maintenance aims to prevent the foreseeable deprivation on the item of property, extending their functioning period and maintaining them in their operational sequence. Thus, maintenance engages in a significant part to support and enhance the resources' availability, altering the system of interest's productivity (Dzulkifli et al., 2021).

Lately, additional consideration has been focused on upgrading and optimizing maintenance in production procedures. The maintenance disbursement can extend between 15% to 70% of production expenses (Kumar et al., 2018; Wang et al., 2020). Moreover, it has been observed that it is a huge possibility to expand the capacity in current maintenance processes (Kumar et al., 2018; Wang et al., 2020). As for that, it is important to have a correct decision in the management as any mistakes in making decisions will harm the organization, especially in terms of maintenance cost (Zavadskas et al., 2017). Moreover, in several organizations, a marginal change in output production might affect substantial monetary ramifications.

On that cause, it can be determined that once the organization intends to choose the most excellent maintenance strategy for an apparatus or item, the factor associated with the maintenance strategies option must be set on the target achieved based on the standard or baseline. Here, the maintenance goals are divided with regards to four attributes: 1) cost on hardware and software includes training personnel; 2) safety of staff, facilities, and environment; 3) reduced breakdowns which include a list of spare parts inventories, production loss with fault identification and 4) feasibility in which labors and reliability procedures (Jafari et al., 2008; Lee & Mitici, 2020).

Moreover, two components of tangible and intangible elements need to be considered in assessing maintenance targets (Kumar et al., 2018). First, for tangible aims, approximation, and quantification, use various instruments to reduce maintenance expenses and increase reliability. Later, for the intangible target, it could not be quantified. However, this can be done by assessing the capable devices laborers accept and improving competitiveness. Hence, evaluation for several intangible aspects can be employed using significant criteria. This technique can uncover a highly effective maintenance strategy with every aspect given simultaneously without considering the tangible or intangible characteristics.

The advent of current research has produced various and equivalent factors that are largely linked to maintainability measures. For example, a small number of maintainability measures are considered throughout the design of the façade in the building that has been listed Ganisen et al. (2015). The list comprises materials selected from durability, sustainability, cleanability, accessibility, and flexibility. In addition, five maintainability criteria have been suggested to be incorporated during the design stage, varying through the layout plan for sufficient safety, maintenance requirements, environment, uncomplicated servicing, and reliable access (de Silva et al., 2012).

However, these show no consensus or concrete arguments with regards to the maintenance criteria. Consequently, several organizations have different maintenance goals; this method is proposed to stipulate the maintenance target by cross-examining the maintenance personnel and managers (Jafari et al., 2008; Mitrofani et al., 2020). Furthermore, the point of reference would guide a poor maintenance verdict to be appraised throughout the design period and subsequently direct to inadequate maintainability.

As for that, decision-making on the effective maintenance strategy is critical as impartial choice of the selection is greatly depends on the criteria that need to be analyzed (Napoleone et al., 2016). Therefore, it is commonly achievable to choose a reasonable judgment by incorporating the experiences and information produced by the expertise regarding the high intricacy of management. Thus, forming a functional decision group is essential to have a collective of information, experience, analysis, and excellent judgment among the experts. However, in forthcoming circumstances which is ambiguous, selecting a management strategy can be a difficult task.

Regarding that issue, the Fuzzy Delphi technique can be proposed for analyzing the subject matter. It can be emphasized that these methods can effectively be used as a measurement tool to solve the uncertainty of the problem studies. The Fuzzy Delphi Method

(FDM) has been improvised as the method and instrument based on Delphi Technique and Fuzzy set theory (Islam et al., 2017). This Fuzzy Delphi method integrates the Fuzzy Numbering Set and the Delphi Method (Murray et al., 1985). The Fuzzy Set theory also works in addition to the Classic Set Theory, where each component in a set follows the binary set (Yes or No) (Zadeh, 1965). The fuzzy set theory also permits granularity and interpretation of each component in a set. The value involved in this fuzzy set is from 0 to 1 or within the unit interval (0, 1) (Baruah & Kakati, 2020). The Fuzzy Delphi Method can process ambiguity concerning respondents' information's predictive items and content (Bui et al., 2020). This method is available to describe the individual characteristics of the participant. In brief, the Fuzzy Delphi Method is applied to get a consensus of experts who react as respondents derived from the manipulation of quantitative methods.

It can be observed that the intricacy of maintenance techniques has risen substantially, and it is relatively owed to current systems of manufacturing that require multiple actions and are reliant on parts of items (Zaranezhad et al., 2019). Due to that, there are remains evidence that analytical and mathematical methods could be restricted to resolve the complicated maintenance issues (Alrabghi & Tiwari, 2015).

However, the determination to use analytical and simulation models can elucidate the invariable obstacle by producing more complex systems (Alrabghi & Tiwari, 2015). Various research has revealed simulation selection to improve maintenance drawbacks throughout analytical and mathematical methods (Lin et al., 2021). Maintenance strategy on selecting the finest method on the electrical equipment for buildings has been adopted using the Fuzzy analytical technique (Gholami et al., 2021). The maintenance system examined will have a high cost of expenditure and more time consumed. However, the method of choice is more value-added and much safer. Therefore, the implementation of the Fuzzy technique can give a clearer view of the complex scenario of building maintenance.

METHODOLOGY

The Fuzzy Delphi Method (FDM) process implemented in the research study for RMAF can be illustrated in Figure 1. FDM aims to get a consensus of experts who react as respondents, which is derived from manipulating quantitative methods. At the beginning of the investigation, the questionnaire was produced according to the eight (8) experts (Table 1). Later, the questionnaire was then distributed to the fifteen (15) experts, including the eight (8) experts interviewed earlier.

Construction of the Questionnaire

As previously discussed, the FDM method is the decision-making method based on an agreement between experts through the questionnaire. Thus, it is essential to construct the questionnaire data integrated with Fuzzy design techniques (Ighravwe & Oke, 2019).

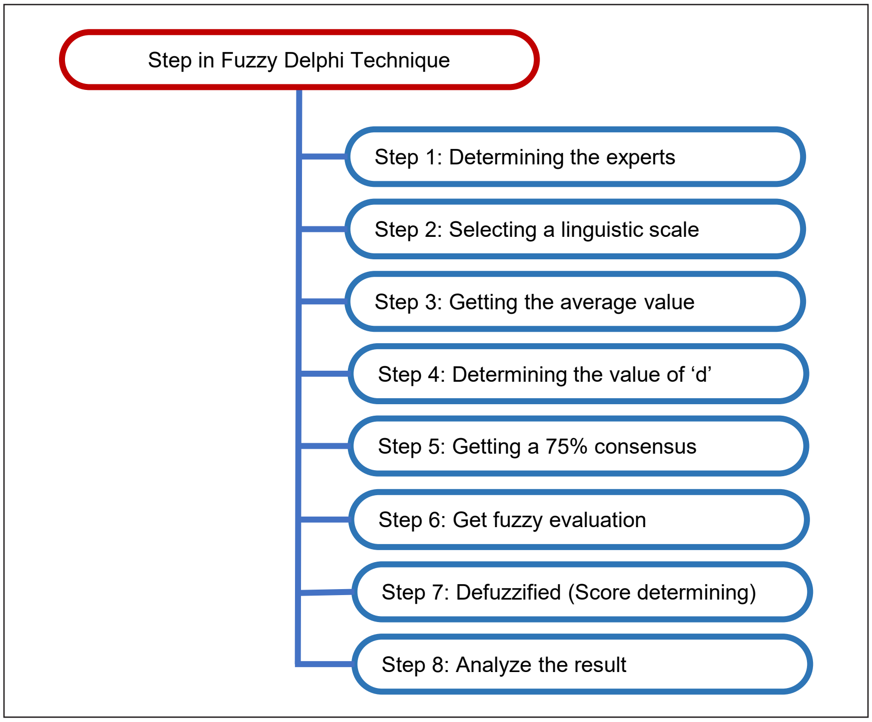

Figure 1. The process of Fuzzy Delphi Method (FDM) for maintenance strategy selection in RMAF

Therefore, to ensure that this survey form meets the research objectives, some experts have been selected to produce survey questions. This survey is based on literature reading, maintenance records, brainstorming sessions, and interviews. A total of eight (8) experts were selected based on their position, work experience, involvement with the project, and their interest to participate in this study (Ganisen et al., 2015). The joint of eight (8) members for the discussion session highlighted the study's direction in choosing the most appropriate maintenance method used in the RMAF. In determining which maintenance method is most effective, the selection is firstly listed and weighted.

Table 1 shows the group of experts' maintenance goals in choosing the most effective maintenance method in the order of priority. The questionnaire was broken down into five sections. Section A applies the background to the respondent. Section B is the section for selecting the most effective types of maintenance implemented in the RMAF. Finally, Section C, section D, and section E select the maintenance goal for each type of maintenance that becomes the weight that affects the type of maintenance in section B.

Each element set by a total of the above eight (8) experts is segregated according to the types of maintenance strategies for Reactive Maintenance (RM), Preventive Maintenance (PM), and Condition Based Maintenance (CBM). This maintenance strategy was implemented by the Royal Malaysian Air Force (RMAF) and later was included to form a comprehensive set of questionnaires.

Table 1
Maintenance goal

Maintenance Goal			
No	*Jafari et al. (2008)*	*Ganisen et al. (2015)*	Specified by eight (8) experts
1	Low maintenance cost	Accessibility (The ability in accessing or reaching parts of a building, facilities or components quickly and without barriers as; and when required.)	Low maintenance cost
2	Acceptance by labours	Durability - The building materials' ability to serve their intended function not only when newly installed but also for some acceptable length of time.	Feasibility (acceptance by labours, technique reliability)
3	Improve reliability	Clean-ability - The ability to easily clean, repair, and replace the building systems/ components to meet aesthetical and functional performance requirements.	Safety (personnel, facilities, and environment)
4	Material availability	Standardization - the attainment of maximum practical uniformity.	Reducing the chance of a breakdown during operations
5	Respond time	Simplicity & Flexibility - Designing a building without complexity, with reduced fundamental parts & hard way.	Respond time

The Election of Experts

Then, fifteen experts were invited to answer the questionnaire (number of experts, k). When deliberating the Fuzzy Delphi study, it is vital to identify and select possible members to comprise the experts' panel (Ludwig, 1997). The choice of members is essential as the study's authenticity is associated with this array of processes. It has been noted that there is no precise measure at this time stated in the literature regarding the choice of Delphi panelists (Hsu & Sandford, 2007). The identification of panelists was based on the knowledge criteria or interest, including the investigation issues' experience. Moreover, the panel's hierarchy or position in the projects and their willingness to participate in the project study are also crucial (Ganisen et al., (2015).

After observation, 15 experts from the RMAF have been chosen literally. They have fulfilled the entire range of prerequisites and were ready to participate in the Fuzzy Delphi analysis. The experts comprised five officers from the Development and Planning department, two officers from the project team, five officers from the Maintenance Office Complex in selected RMAF air-based, and three officers from the Implementation Department of Defense Engineering Services. The panel members and their affiliations are listed in Table 2. The nominated experts constituted a broad range of professionals in the building industry of RMAF and, therefore, can offer a fair point of view on the Fuzzy Delphi survey.

Each professional has adequate knowledge, position, and expertise in the building industry. Table 3 shows the amount of the respondent's total years employed in the

Table 2
List of the panel expert for the Fuzzy Delphi study

No	Area of Expert	Number
1	Architecture Civil	2
2	Engineering	4
3	Mechanical Engineering	2
4	Electrical Engineering	2
5	Building Maintenance	3
6	Quantity Surveyor	2
	Total	15

building industry, position or hierarchy, and the number of projects involved. The knowledge and area of expertise, sufficient working experience, senior job positions, and projects involved by the selected experts were certified in this Delphi research's validity. Eight experts interviewed in the first step (during the forming of the questionnaire) were also involved in answering the survey.

Table 3
Respondent classifications by years working, position and number of projects involved in the building industry

Years of Experience	No	Project Involved	No	Position	No
0-5	2	0-5	2	Deputy Director	1
6-10	6	6-10	2	Vice Director	1
11-15	2	11-15	7	Engineer	3
16-20	2	16-20	1	Architect	1
20-25	1	20-25	1	Maintenance Officer	6
26-30	1	26-30	1	Quantity Surveyor	1
30+	1	30 and above	1	Facility Manager	2
Total	15		15		15

Linguistic Scale Determination

In the survey, a linguistic scale was selected from a seven-point linguistic scale ranging from 'very strongly disagree' to 'strongly disagree,' 'disagree,' 'not sure,' 'agree,' 'strongly agree,' and 'very strongly agree.' The higher the scale, the more precise and accurate the data obtained (Islam et al., 2021). Later, after the questionnaire has been answered in the Likert scale, it has been converted to the Fuzzy scale. Table 4 shows the seven-point

Table 4
Seven-point linguistic scale

Linguistic Variables		Scale Fuzzy		
		Min Value	Most Plausible Value	Max Value
1	Very strongly disagree	0.0	0.0	0.1
2	Strongly disagree	0.0	0.1	0.3
3	Disagree	0.1	0.3	0.5
4	Not sure	0.3	0.5	0.7
5	Agree	0.5	0.7	0.9
6	Strongly agree	0.7	0.9	1.0
7	Very strongly agree	0.9	1.0	1.0

linguistic scale chosen in this study incorporated with the fuzzy triangular numbers (TFNs) (n values) with n_1 denoted the minimum values, n_2 denoted the most plausible value, and n_3 representing the maximum value for every linguistic variable. Here, the fuzzy scale is more appropriate to utilize than the crisp numbers because they signify the data more rigid in the actual condition (Tarmudi et al., 2012). Therefore, it can be denoted that the maintenance strategies are using the same linguistic scale.

Getting the Average Value and Threshold Value, d

Later, the average value (m) was determined for every questionnaire for m_1 is the average for minimum value, m_2 is the average for most plausible value, and m_3 is the average for maximum value for all the questionnaires. Later, the value of 'd' (threshold value) must be determined in the research study according to Equation 1.

$$\mathrm{d}(\bar{m},\bar{n}) = \sqrt{\left[\frac{1}{3}(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2\right]} \qquad (1)$$

Where:

$\mathrm{d}(\bar{m},\bar{n})$: Average threshold value

n_1, n_2, n_3: Fuzzy value

m_1, m_2, m_3: Average Fuzzy value

It is denoted that if the value of *d* is $d<0.2$, then all the experts had reached a consensus agreement. If the value of *d* is $d>0.2$, the researchers had to go over the procedure again. Moreover, if the average expert assessment data is less than or equal to the threshold value, all experts are considered to have reached the consensus (Cheng & Lin, 2002). Even if *d* is more than 0.2 but still does not reach 0.3, the value is still considered lesser or equal to 0.2.

Consensus of Expert

The results obtained for the threshold value (*d*), the survey with more than 0.3, will be discarded. The number of respondents who acquired threshold value, $d < 0.3$ with the respondent's total was calculated in percentage value. It should be considered that the conditions in FDM must be complied by getting 75% of consensus from the experts (percentage of the threshold value, *d* for each participant does not exceed 0.3) for each item in the questionnaire. It was agreed that a 75% consensus would be required to display an agreement between the experts (Cheng & Lin, 2002). If an item does not reach an agreement percentage by an expert exceeding 75% in that case, the item will be rejected, reviewed, and improved before the responding process is repeated to the same respondent. It is aimed at the only items that impact the selection of the maintenance types assessed.

Fuzzy Evaluation and Defuzzified

After all the above process has been completed, the step is for Fuzzy evaluation. It is one of the approaches for defining the ranking of an item. This phase is more complicated as it includes complex numbering and an alternative method of employing a mathematical formula to determine a rank. It is described as the defuzzified process, which is the score determining process. This method aims to assist the researcher in gaining the point of need, the importance and level of a variable, and the sub variable required. This ranking procedure will help generate data according to the needs based on the expert consensus that the study's respondent serves. The symbol for defuzzification is A_{max}. Defuzzification is also known as a Fuzzy score. Three formulae can be applied in the defuzzified process to determine the ranking/ scoring of the items as in Equations 2-4:

$$A_{max} = 1/3 * (m_1 + m_2 + m_3) \quad (2)$$

$$A_{max} = 1/4 * (m_1 + 2m_2 + m_3) \quad (3)$$

$$A_{max} = 1/6 * (m_1 + 4m_2 + m_3) \quad (4)$$

Where,
A_{max}: Average Fuzzy score
m_1, m_2, m_3: Average Fuzzy value

For this study, Equation 2 has been selected to evaluate the Fuzzy scores of RMAF maintenance strategy selection.

RESULTS AND DISCUSSION

Two conditions need to be fulfilled in employing the FDM. First, using a threshold value, '*d*' and getting consensus from the expert, which is more than 75% before the ranking of an item, can be determined using the analysis tool of FDM (Hasan et al., 2017). This study implements FDM separately for each maintenance strategy to interpret the data. Later, after all the calculations of Fuzzy scores were obtained, the results were converted into a bar chart to interpret each maintenance strategy's differences in the research study.

Figure 2 shows the Fuzzy Score for maintenance strategy implemented in the RMAF organization. Based on this result, PM has the highest Fuzzy Score, 0.789. CBM follows with 0.767 Fuzzy scores and RM with 0.747 Fuzzy scores, respectively. Hence, it can be interpreted that PM was the most suitable maintenance strategy implemented in the RMAF organization, which has been agreed upon among 15 experts through FDM. Every decision in choosing the most practical maintenance strategy mentioned above was referred to the five maintenance goals, as stated below:

(a) Low maintenance cost (hardware, software, and personnel training)

(b) Feasibility (acceptance by laborers and technique reliability)
(c) Safety (personnel, facilities, and environment)
(d) Reduce breakdown (spare parts inventories, production loss, and fault identification)
(e) Respond time

Figure 3 shows the maintenance goal ranking for each maintenance strategy. As we can see, the green color chart, which is presented as a low maintenance cost in Preventive Maintenance (PM), has the highest Fuzzy score compared to others, which is 0.92. Therefore, the experts have chosen the PM as the most suitable maintenance strategy implemented in the RMAF organization due to low maintenance costs.

Basically, after considering long-term maintenance costs, it can be deduced that the maintenance strategy was at the lowest expense. Most of the buildings in RMAF required 24 hours operation time. If any failure or interruption occurred to the RMAF building or asset, it would jeopardize the country's safety. For example, if the generator's problem occurred, this would contribute to a power failure in supporting the electricity to the radar building. Consequently, implementing Preventive Maintenance (PM) as the scheduled maintenance or periodic maintenance will

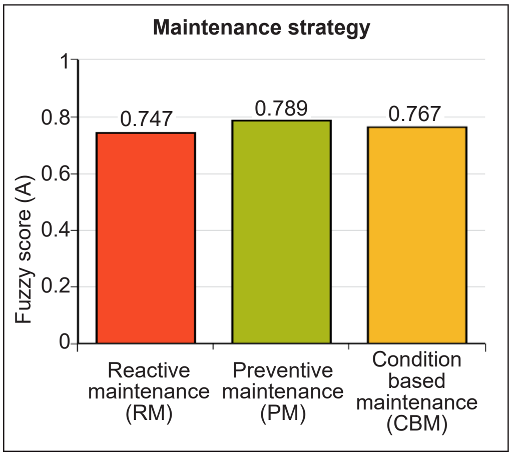

Figure 2. The fuzzy score for maintenance strategy implemented in RMAF

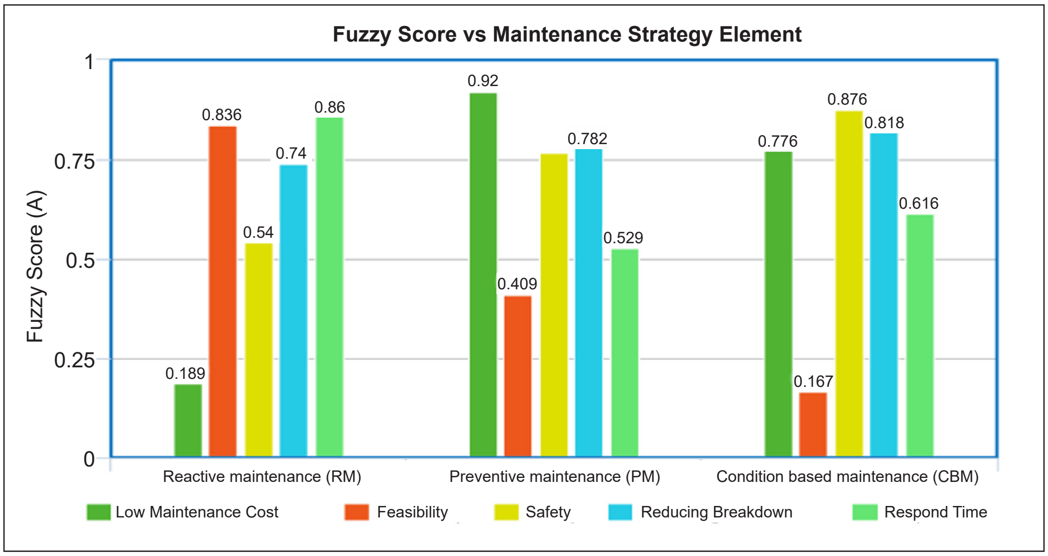

Figure 3. Maintenance strategy ranking and its goal

reduce failure to the equipment (Najafi et al., 2021). However, if no appropriate action is taken, it will affect other pieces of equipment in the long run. Thus, it will contribute to the increment in maintenance expenditure. Therefore, the cost would be the main factor in selecting the maintenance strategy.

Like other government organizations, the maintenance allocation budget for RMAF in keeping their building and assets in good condition was given yearly. However, this spending distribution was limited and needed to be wisely managed and optimized. Based on this constraint, the experts had chosen the low maintenance cost as an indicator in selecting the PM as the most suitable maintenance strategy in the RMAF organization. Therefore, selecting suitable maintenance strategies combined with highly economical materials can prolong the shelf life of equipment and maintainability with less expenditure (Ferreira et al., 2021).

The second highest Fuzzy score for low maintenance cost is CBM, with a Fuzzy score of 0.776. CBM was the most effective maintenance method since it can detect very early failure symptoms before the equipment fails to operate. However, the equipment used to detect the failure was too expensive. Moreover, experienced and skilled people are needed to interpret the data produced by the equipment. This type of maintenance can reduce failure up to zero failure since early malfunction detection will be done, and replacement of the defected part takes place before it can affect other equipment. Thus, in terms of cost, it saves money (Jiang et al., 2021; Najafi et al., 2021). However, in the RMAF organization, this type of maintenance is only implemented in the selected building or equipment due to the current condition, for example, old equipment. The lowest Fuzzy score for low maintenance cost was RM. This method is the lowest in the Fuzzy score regarding cost as the type of maintenance applied if failures occur. It means that when the failure happens, then all the related parts will be rectified.

When a failure occurs indirectly, it also contributes to the defect of other equipment; for example, overheating happens in the Uninterruptible Power Supply (UPS) system. This failure will only be noticed when UPS fails to function properly (Aamir et al., 2016). Sometimes, it will cause burning, and directly it will affect other equipment. Other than that, an average Fuzzy Score value can be calculated from the score value of the maintenance goal for each maintenance strategy. From the results obtained, the highest average Fuzzy score was PM (0.6816), followed by CBM with an average of Fuzzy Score 0.6514 and RM (0.633), accordingly. It means that the expert’s maintenance goal in this study is most suited with PM compared to other maintenance strategies. The maintenance goal in Figure 3 has been breakdown individually in the bar chart for further analysis.

Figure 4 shows the Fuzzy Score of low maintenance cost of maintenance strategy. Based on this result, PM has the lowest maintenance strategy cost than other maintenance strategies followed by CBM and RM. Referring to Figure 2, PM was selected as the most effective maintenance strategy than other maintenance strategies. Looking at the

Fuzzy Scores for the maintenance goal–low maintenance costs, it is clear that PM is an effective strategy due to low maintenance costs. Since these maintenance activities are more organized with financial planning, they can be made more accurately (Gan et al., 2021). Based on the Fuzzy Score for CBM, this maintenance strategy fell second after PM. Theoretically, CBM is more effective and cost-effective than other maintenance strategies (Najafi et al., 2021). Since the CBM maintenance concept only focuses on monitoring equipment that shows only the fault symptoms (Kumar et al., 2018). However, the cost of purchasing CBM equipment is very expensive. An additional cost is also needed to train specialist workers in interpreting data from the CBM equipment from time to time. Indirectly, it is not the best method in saving the cost of maintenance.

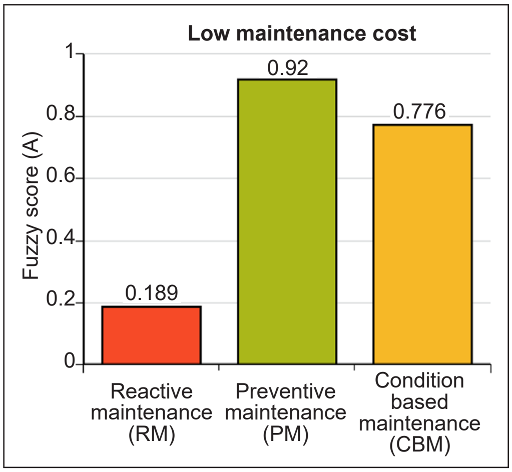

Figure 4. Maintenance goal - Low maintenance cost

Experts have chosen RM as the lowest priority maintenance strategy compared to other maintenance strategies within the RMAF organization. Repair works will only be executed later when the equipment malfunctions or damage happens (Niu et al., 2021). There are often happens if there is any impairment to a device; it may also damage other equipment. Additionally, this type of repair process uses the trial and error method. The repair procedures are based on the skills and experience of the technicians who make the repairs. Furthermore, the technician could not accurately assess the stage of the equipment.

The feasibility of the maintenance strategy in this study is the acceptance by labor and technique reliability (Yoon et al., 2021). Even if the PM is ranked second in its preference (based on fuzzy scores) in feasibility maintenance goals, however, this type of maintenance is still selected by experts as the most effective maintenance in the RMAF organization. It is because most high-value equipment in the RMAF is scheduled regularly. For example, radar equipment is worth millions of dollars. These equipment types are on schedule, so Maintenance Goal- Feasibility is not the main factor for maintaining PM types within the RMAF organization. In Figure 5, RM shows the highest Fuzzy score, but the damage often involved with this type of maintenance is small such as a short circuit. Although Maintenance Goal-Feasibility for this kind of maintenance is high, the impact on the operation and financial organization of the RMAF is not significant. CBM shows the lowest Fuzzy score in Maintenance Goal—Feasibility. Despite being the lowest, it was still chosen as the second maintenance strategy of its priorities, resulting in Figure 2. It is due to the implementation of this type of maintenance requiring expensive equipment and a highly skilled workforce and requiring special storage space. Only certain equipment uses CBM as a maintenance method in the RMAF organization. This study's safety in maintenance strategy refers to personnel, facilities, and environment (Dzulkifli et al., 2021).

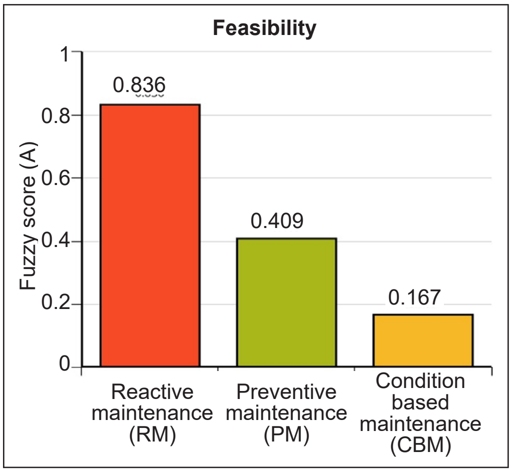

Figure 5. Maintenance goal – Feasibility

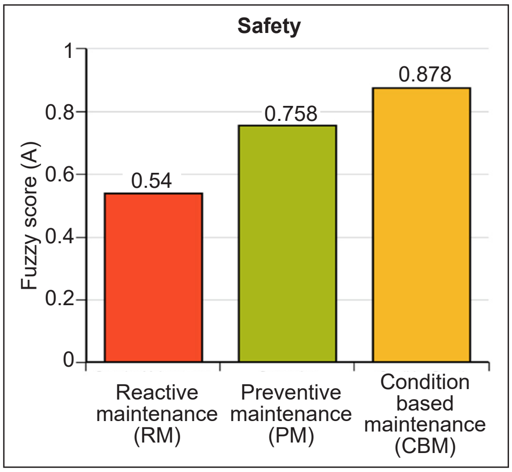

Figure 6. Maintenance goal – Safety

Safety is a key factor in every organization as buildings deteriorate due to aging, and many others encounter defects (Chan, 2019). Based on Figure 6, the Fuzzy score shows PM is the second-highest position. While Maintenance Goal-Safety, PM was second in priority, experts selected PM as the most effective maintenance to be implemented within the RMAF organization. The PM type maintenance does not require technicians to make serious repair work. Only servicing work according to the schedule should be carried out. Therefore, in terms of safety, the PM is adequate to be implemented within the RMAF organization. CBM obtains the highest Fuzzy scores for Maintenance Goal—Safety. CBM only involves monitoring symptom work before a device is damaged. Only equipment showing signs of defective will be changed according to the equipment's symptom level. Although CBM is getting Fuzzy high scores, it is still chosen as the second maintenance strategy in priority, as shown in Figure 2. Only certain hardware that uses this type of maintenance and the impact of security have a huge impact on the RMAF organization. RM gets the lowest score for Maintenance—Safety Goals. This type of maintenance involves repair work after the equipment is damaged. Therefore, this type of maintenance had the lowest score in terms of safety. Figure 2 shows that RM is the last rank as an effective maintenance strategy for the RMAF organization.

Figure 7 shows the Fuzzy Score for Maintenance Goal—Reduce breakdown in maintenance strategy. This Maintenance Goal—Reduce breakdown refers to the frequent breakdown in RMAF equipment. Despite being ranked second in priority order in FDM, experts chose

PM as the most effective maintenance method. Performing the maintenance of a scheduled type can reduce damage, especially recurring damage. Compared to CBM, PM shows lower positions than CBM in terms of Maintenance Goal—Reduce breakdown. However, this type of maintenance is easy to implement against CBM, requiring expensive equipment and skilled workers to analyze data from CBM equipment. Based on Figure 2, RM is in the final ranking of FDM's decision compared to other maintenance strategies as this type of maintenance involves repairs after damage. Thus, the probability of repeating damage and other loss will be high. Therefore, following the case in this research study by implementing multi-criteria decision-making prolongs the sustainable maintainability of the buildings (Ighravwe & Oke, 2019).

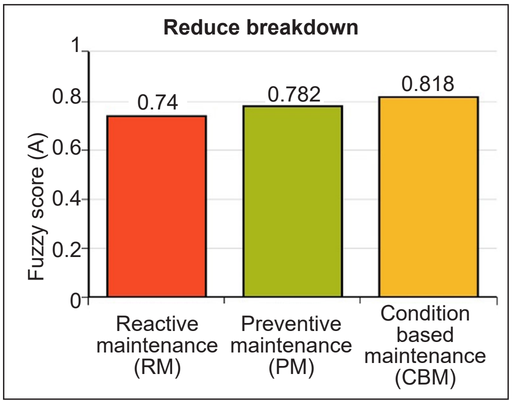

Figure 7. Maintenance goal – Reduce breakdown
Source: International Coffee Organization

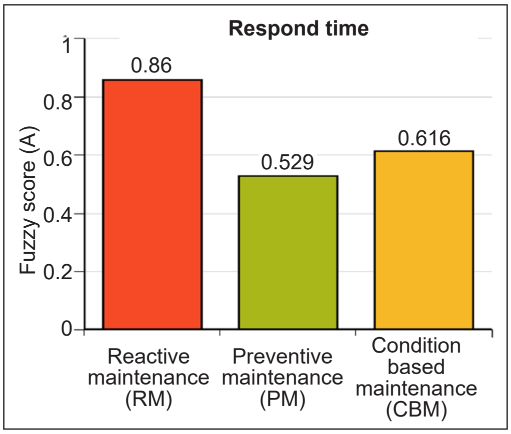

Figure 8. Maintenance goal – Respond time

Respond time was also the goal that must be considered when selecting the most suitable maintenance strategy implemented in the RMAF organization. Respond time refers to the time taken to fix the damage starting from the damage occur. Based on Figure 8, PM is at the lowest position for Maintenance Goal—Respond Time. Nevertheless, the PM remains the most effective maintenance strategy method. It is because implementing the PM's maintenance strategy can reduce the damage. Hence, response time is not considered the main criteria of the financial allocation for maintenance within the RMAF organization. CBM ranks second on Maintenance Goal-Respond Time as compared to RM.

RM shows the highest fuzzy score for Maintenance Goal—Respond Time. However, it has been chosen as the lowest maintenance method for the RMAF (Figure 2). Due to high maintenance costs, emergency damage is rare except for natural disasters. Additionally, this kind of maintenance requires a high initial cost to be implemented. Moreover, it is crucial to manage uncertainty due to the risk of failure, which will add to the high expenditures (Love & Matthews, 2020).

CONCLUSION

In conclusion, all maintenance strategies implemented in the RMAF organization have been analyzed using FDM. Experts have chosen the most effective maintenance strategies implemented in the RMAF organization based on Fuzzy scores for each maintenance strategy through FDM. FDM results indicated that PM obtained the highest Fuzzy score of 0.789, followed by CBM of 0.767 and RM with 0.747 Fuzzy scores. It has been found that all maintenance strategies implemented in RMAF organization have their strength which will contribute to the following factors: low maintenance cost for a long time reducing the chance of a breakdown during operation and safety-related with personnel and facilities, environment. The maintenance strategies also affect the feasibility, especially acceptance by labor, technique reliability, and the ability to be implemented in both building and equipment with response time starting from failure in the RMAF organization.

The main factor for the experts' in choosing PM as the most effective maintenance strategy is low maintenance cost. RMAF is a non-profit organization; thus, the maintenance allocation depends solely on the government budget. In this situation, PM is seen as the most cost-effective maintenance strategy for the long term. CBM is the second most efficient maintenance strategy due to the highest Fuzzy Score in reducing the chance of breakdown during operation. Even though maintenance allocation is the most important factor to be considered, the functionality of buildings and equipment in RMAF cannot be ignored. RM obtained the lowest Fuzzy score compared to other maintenance strategies. Hence, the experts have agreed that RM is the least effective maintenance strategy in the RMAF based on the financial allocation of maintenance. However, in response time data from FDM, RM was the most efficient method for unpredictable damage. Hence, to make it successful, the RMAF should prioritize the maintenance activities within its organization based on FDM's decision to see the effectiveness of this analysis.

The study observed that the selection of maintenance strategy depends on the way forward of an organization (Carnero & Gómez, 2017). It is observed that the main constraint in RMAF building maintenance management is financial issues. At the same time, RMAF building and equipment need to function for 24 hours without failure. Therefore, it is recommended that this maintenance strategy be combined according to the current situation in RMAF. Moreover, the maintenance costs are only stated generally by experts.

Consequently, a detailed study of these maintenance costs should be conducted to determine the balance of rates between cost savings and its benefits whether the savings are worth it or not compared to the operation of the RMAF.

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