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A review of multi-criteria decision making methods for enhanced maintenance delivery

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Abstract

Conventionally there is a strong relation between manufacturing and services in complex engineering industries. For companies which aim to last in the competitive manufacturing market choosing appropriate decision making methods to improve their maintenance delivery has a vital role. The aim of this paper is to review Multi Criteria Decision Making (MCDM) models, evaluate each method and do a critical comparison to assess them from a maintenance management point of view. The first section of this paper reviews MCDM methods in different literature, and then the second part develops a set of criteria to classify different techniques. At the end methods are compared based on developed criteria. This paper assesses different MCDM models, and provides a framework to select approaches for maintenance management.

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Keywords: Multi criteria decision making, Support contract and Maintenance management.

1. Introduction

Direct cost of maintenance for companies has been increasing lately. Manufacturing equipment has increased complexity and requires skilled personnel for their maintenance, leading into an increase of the maintenance costs [1].

In Pintelon and Gelders[2] maintenance activity is defined as “all activities necessary to restore equipment to, or keep it in, a specified operating condition.” The main objectives of maintenance management and activity for industries are: (a) maximizing capacity and product volume by affecting the availability and reliability of equipment, (b) to optimize environmental and employee safety [3]. The above objectives have direct impacts on industries’ profitability and it has been shown in both European [1;3] and American industries [5]. There are several maintenance management approaches (e.g. reliability centered maintenance, integrated life cycle, reactive maintenance etc.). As a result of profitability targets, decision making processes support with identifying different maintenance approaches and activities that fits the objectives of a company or an organisation [6].

There has been some efforts to bring decision making methods and models to different aspects of maintenance management in the past (e.g.[6;8]). However, as it is a new and broad topic, there are still plenty of gaps for modelling different aspects of it such as outsourcing different part of maintenance management approaches which can be developed and worked on. Section1 of this paper covers a review for MCDM methods in different literature; section 2 develops a set of criteria to classify different techniques. Finally section 3 covers a comparison among all discussed methods based on developed criteria.

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1. Multi criteria decision making techniques

In generic terms in common decision making processes follow eight steps for decision making process [9; 10], which are presented in Fig1. To achieve the goal and objectives, choosing the appropriate decision making method which fits the problem type is the first step in the decision making process [12]. To select the best method they must be compared based on different types of problems and highlight their pros and cons. In the second step, the requirements of a decision should be defined based on expert's judgments or any other technical restraints.

For the third step, goals must be clarified and the most important part is that goals must be considered positively (i.e. production line should produce 7 units per hour and not produce less than 7 unit per hour [11].

The forth step is defining alternatives. Alternatives are the methods which change the preliminary condition into preferred condition [10].

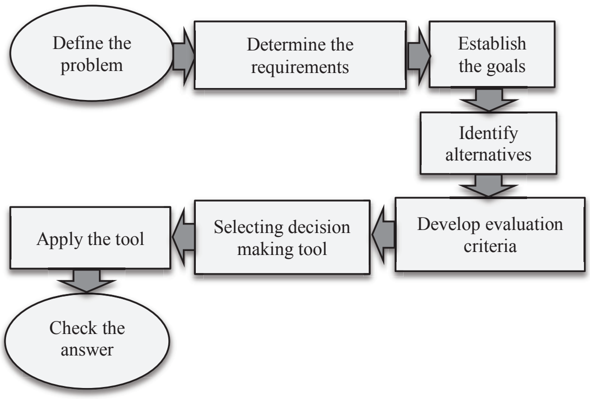

Fig1.General decision making process [10], [11]

Often none of the alternatives fit perfectly to achieve goals. The alternative that best suits the goals can be selected by evaluating the different alternatives against a set of criteria[13]. These criteria help to differentiate among alternatives and select the most relevant one based on decision maker's preferences. The next step for the decision making process involves defining and assessing the criteria.

In Baker et al., [11] some specifications for criteria have been described. While defined criteria have these specifications, distinguishing among the alternatives and selecting the best one can be performed more easily with more accuracy assigned to the defined goals. Described specifications are as follow:

- Able to distinguish among alternatives
- Complete enough to cover all goals
- Non-redundant
- Few in numbers
- Operational and meaningful.

In the next step, selecting the decision method should be made. There are various decision making methods which the most common in use will be described in the following section. In the last step, alternatives should be assessed against criteria to choose the most suitable one [6].

1.1. Decision making methods

The base trait of all Multi Criteria Decision Making (MCDM) methods is a decision table. According to Fulop[6] for a problem with N criteria (C) and M alternatives (A) the decision table will be drawn as in Table 1 while a_{mn} is the score of alternative n related to criteria m;

Table1. Decision table

	A_1	...	...	A_n
C_1	a_{11}	a_{12}	…	a_{1n}
.	…	…	…	…
.	…	…	…	…
.	…	…	…	…
C_m	a_{m1}	…	…	a_{mn}

It has been claimed in Mareschal [14] that weights can be assigned to each criteria and bring weight into account for better and more accurate decision making in both qualitative and quantitative data. However, assigning weights to qualitative criteria can be affected by decision maker preference and can vary extremely from one decision maker to another. To cover this weakness Saaty [15] suggested a numerical scale (0-9) to transform qualitative data into quantitative , while 1 is described as equal importance or preference and 9 is describing a situation with extreme importance or preference [13].

Criteria weighting can lead in an accurate decision making process for quantitative criteria, but on qualitative criteria this could be considered a disadvantage [16].

There are several decision making methods for different type of problems.Based on a research through Scopus database with following keywords; Decision making and maintenance management with name a method each time e.g. Analytic Hierarchy Process (AHP), PROMOTHEE etc. it was found out that the most in common methods that are used in publications are AHP, ELECTRE (elimination ET choix traduisant la realite), PROMOTHEE and they will be discussed in this paper. According to the result of above search through Scopus database Table 2 shows the number of used decision making method in previous publications in the maintenance management field.

Table2. Number of publications for each method

	Total	2015	2014	2013
AHP	179	12	32	25
PROMOTHEE	46	6	15	11
ELECTRE	158	11	36	22
SMART	9	0	1	0
TOPSIS	2	0	0	0

In the following sections each of these methods will be briefly described and compared at the end.

1.1.1. Analytic Hierarchy Process (AHP)

AHP was proposed by [15], the basic idea of this method is leaning on pairwise comparison based on the eigenvector. Marcus and Minc [17] defined eigenvector as: " eigenvectors are a special set of vectors associated with a linear system of equations (i.e., a matrix equation) that are sometimes also known as characteristic vectors, proper vectors, or latent vectors. It is widely in use for subjective assessments by practitioners and academics [18].

As a part of structuring the problem in this approach, the decision problem should structure into a hierarchical model. The model must show the relation between the goal, criteria and alternatives [13]. In simple words, the AHP method is a pairwise comparison in small part of hierarchical structure and then between higher level of hierarchical structure.

The main disadvantages of this method are: weight of each criterion has a significant effect on the final alternative score, as weighting criteria in this method is judgmental and based on decision maker preference so accuracy in this method can be widely varied in subjective problems[11]. However, there has been some efforts to cover these weak points; e.g. [16; 17].

1.1.2. PROMOTHEE

Brans and P. Vicke [18] and [19] proposed the decision table which was the starting point for the PROMOTHEE method. POMOTHEE is an outranking method. An outranking method does not eliminate any alternative in pairwise comparison instead it puts the alternatives in an order according to criteria and decision maker preference. The advantages of this method are simplicity, clearness and stability [21].

This method can deal with finite number of actions to gain partial preorder (PROMOTHEE I) or a complete one (PROMOTHEE II) [21].

As Brans et al. [21] and Mateo [13] claimed, the PROMOTHEE method has five main steps: "in the first step, a preference function showing the preference of the decision maker for an action a with regards to another action b, will be defined separately. The second step concerns the comparison of the suggested alternative in pairs to the preference function. As a third step, the outcomes of these comparisons are presented in an evaluation matrix as the estimated value of every criterion for every alternative. The ranking is realized in the two final steps: the fourth step includes the PROMOTHEE I method application for partial ranking and afterward the fifth step includes PROMOTHEE II method for complete ranking of the alternatives."

The main advantage of this method is that there is no demand for normalization of scores. On the other hand, weight must be defined separately as the weighting techniques is not part of this method [6].

1.1.3. ELECTRE

ELECTRE was devised in 1968, which is an outranking method and is based on partial aggregation. The idea of this method is ranking alternatives based on concord and discord index that are calculated with extracted data from a decision table. As Mateo [13] mentioned this method has 4 main steps. In the first step, weight must be given to each criterion regarded to a normalization theory that sum of all weights must be equal to 1 and a threshold function must be established. In the second step, concordance and discordance index for a pair of alternatives must be calculated. In the next step outranking degree for each pair of alternatives must be calculated based on concordance and discordance index. Finally the partial ranking will be made by considering all pairs of alternatives. The biggest disadvantage of this method as Hui-Fen Li [22] claimed is: "the weakness of normal ranking of ELECTRE is that it requires an additional threshold to be introduced and the ranking of the alternative depends on the size of this threshold for which there exists no 'correct' value". On the other hand, the main advantage of the method is that ELECTRE can handle both quantitative and qualitative data for outranking alternatives [13].

2. Classification in MCDM

To select the appropriate decision making method for any type of problem, understanding the decision making classification seems vital.

For general categorisation of MCDM methods, in the first step MCDM can be categorised as Fig 2 [23].

As Gal [22] and Korhonen et al. [23] pointed out MCDM can be easily categorised by a number of answers; 1-innumerable when the admissible answers are infinite and 2-numerable when admissible answers are finite.

In general all MCDM methods can be categorised in two main subgroups: 1- multi attribute decision making (MADM) and 2- multi objective decision making (MODM) [24]. Comparison between MODM and MADM has been presented in Table 3.

Table3. Comparison between MADM and MODM

	MADM	MODM
Criteria	Attributes	Goals
Goal	Clear	Not Clear
Attribute	Clear	Implicit
Limitations	Not clear	Clear
Options	Finite/Clear	Infinite/Unclear
Interactions with decision maker	Low	High

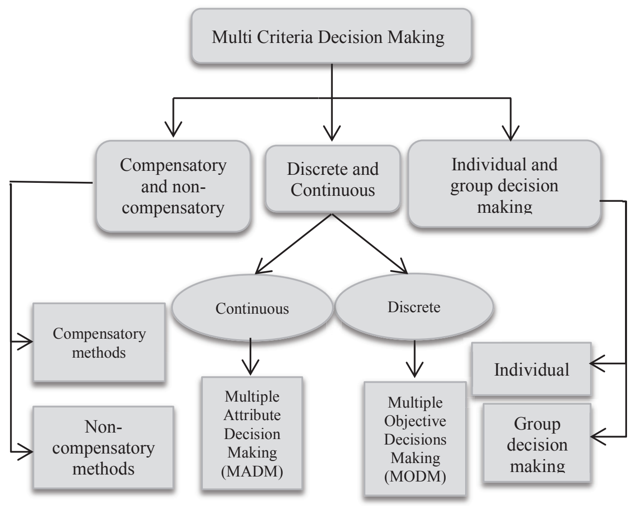

Fig2.MCDM Category based on data processing [23].

In maintenance management possible answers are finite and MADM is the category which must be chosen. One more step further for categorising methods is vital to choose the appropriate method based on the problem type.

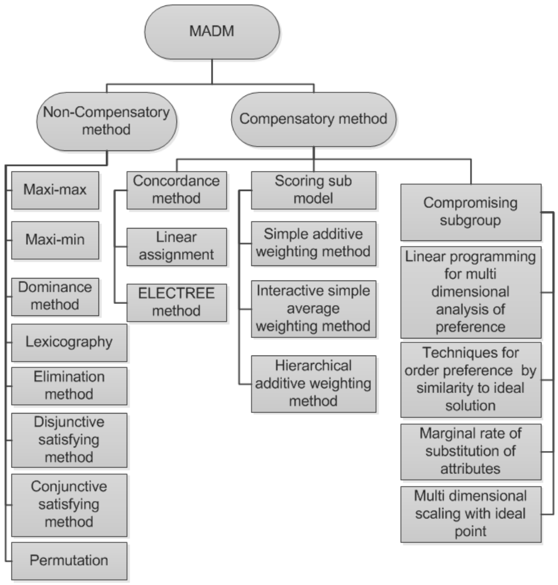

Fig3.MCDM Category based on data processing.

In this step, MADM is categorised based on the data processing type which helps to select the most suitable method based on attribute's behaviour. This category has been illustrated in Fig 3.

As in maintenance management criteria can be defined from different perspectives, appropriate method cannot be selected just from the data processing point of view. Availability of data can be another aspect for selecting the most suitable method. This categorisation has been illustrated in Fig 4.

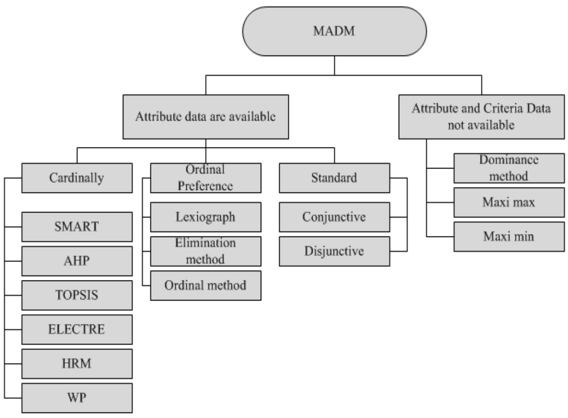

Fig4.MADM methods categorized in data availability perspective

Another aspect which can help to categorize the MCDM in maintenance management is the decision maker's preference. It means if decision makers prefer to consider all possible solutions and just outrank them or they want just to select the best option and not consider other options. There is a demand for selecting a decision method based on this constraint and following illustration is the flowchart for selecting the method based on that constraint.

There are several different methods for categorizing, which is beyond the scope of this paper to present. However, the above categories are the most helpful in selecting the best method for decision making in different aspects for maintenance management.

3. Comparison among methods

SMARTS is a simple method based on allocated weights to the alternatives. As Edwards and Barron [26] mentioned: "This method is easy to use and also a good trade-off method between modelling error and elicitation error ." However, this method is the simplest form of all multi attribute utility theory (MAUT) which face with plenty other issues like uncertainty rate, problem's complexity etc.

According to Mateo [13]: "the objective of using AHP is to identify the preferred alternative and also determine a ranking of the alternative when all the decision criteria are considered simultaneously".

While [13] believes that "PROMOTHEE method uses the outranking methodology to rank the alternatives combined with the ease of the use and decreased complexity. Based on extensions of the notion of criterion, the method is well adapted to a problem where a finite number of alternative actions are to be ranked considering several criteria".

For an unstructured problem, AHP is the most appropriate method if the decision maker prefers to have pairwise comparisons between components of problem which has been broken down [27].

On the other hand, PROMOTHEE is an outranking method which allows decision maker to choose the best alternative from outranked existing alternatives.

The most significant part of this method is that, it can outrank alternatives in a partial preorder or complete preorder. This ability makes the method more powerful and operational in different problem solving conditions [21]. In addition, there is another important part in the PROMOTHEE method, stability assessment at the end of decision making process can be done to avoid any extra deviation in decision making progress.

ELECTRE is the most common Multi Attribution Utility Theory (MAUT) method which contains information among the criteria and information within each criterion, this method is based on partial aggregation of preference. It can be used when decision maker cannot be rational in some aspects of decision making; another point is that ELECTRE method can deal with qualitative and quantitative data with high uncertainty. The most significant point about ELECTRE is that, this method is less sensitive to any changes in data in comparison to other methods, which makes it more stable and reliable than others. Also as this method has different Subgroups like ELECTRE I, II, III, IV and each has their own strong and weak points, the method is applicable in different sectors relatively easily. Table4 represent the comparison among the methods.

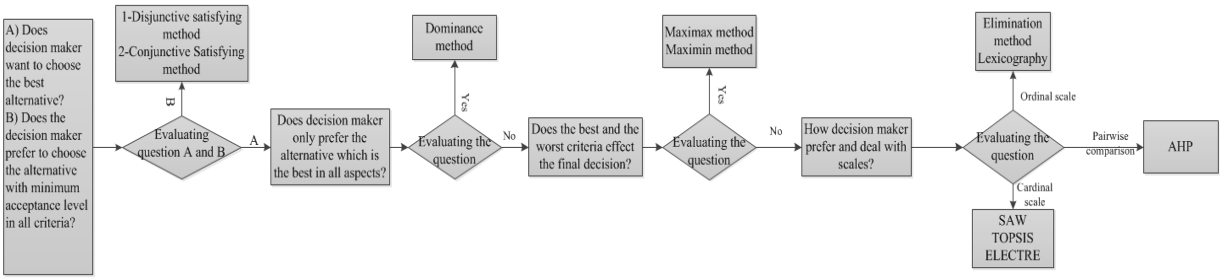

Fig5.Process of selecting MCDM method based on decision maker preference

Almeida [28] has developed a model for spare part provisioning in maintenance. As it was presented in the above paper, risk and costs are two main criteria which are qualitative and as risk and cost needs to be considered with high uncertainty, MAUT has been chosen which can deal in this situation.

Table 4. Comparison among different methods based on developed criteria.

	Outranking method	Data type	Considering Uncertainty
AHP	Pairwise comparison	Qualitative/ Quantitative	Meduim
PROMOTHEE	Partial/ Complete preorder	Quantitative	Meduim
ELECTRE	Partial aggregation	Qualitative/ Quantitative	High

Almeida [29] has developed a model based on decision making techniques for outsourcing maintenance. In this case cost, quality of service, delivery time and confidence in quality commitment are the criteria in the model. Cost and delivery time are quantitative and quality and confidence of quality commitment are quantitative, also selecting service providers needs an outranking method to consider all options without elimination. The method which has been applied in above study is ELECTRE which can provide all mentioned conditions.

In [30] PROMOTHEE method has been considered to have the optimized cost benefit in preventive maintenance strategies. For developing a model in this base, as authors mentioned that cost benefit is a quantitative approach and complete preorder is required in selecting strategies.

In Braglia et al. [31] AHP has been used to develop a model for classification of spare part inventory. In the first step, they assessed criticality of spares then they used a cost estimation method to classify the spares and redefining stock level for all spare part is the final step.

In the developed model three alternative (critical, important and desirable) scenarios exist and several criteria (e.g. production loss, quality problem, domino effect etc.). AHP is the most suitable method for developing this model as pairwise comparison is needed in this case to find out the most critical spare part, uncertainty does not have a critical role in criteria and also data are combination of qualitative and quantitative.

Fig 5 shows the different steps for selecting the method. It must be mentioned that the process which is shown in Fig 5 is just based on the decision makers' preference; uncertainty rate and problem complexity has not been considered through selecting a method.

After clarifying the decision maker's preference in selecting the best method or a method with minimum acceptance level in different criteria, it must be clarified if decision maker is looking for an alternative which is the best in all criteria or not. As it happened rarely in the maintenance sector that an alternative is the best in all criteria, giving the importance to the best and worst criteria can be a good option for the decision maker. However, it can extremely affect the final decision. So in the next step, it must be clarified if the decision maker is keen to give importance to the best and worst criteria or not. Ordinal, cardinal or pairwise comparisons among alternatives are three different scales which must be clarified based on the preference of the decision maker in the last step.

4. Discussion and Conclusions

After reviewing different literature, it was found out that, reason of selecting the decision making method has been briefly described in almost all literature. Also it has been realized that there is a gap in general overview for selecting a decision making method in maintenance management based on decision maker preference.

Presented paper can fill the identified gap in the literature by presenting general overview of different decision making methods, although this paper can help industries to select a method for their maintenance management to improve their decision efficiency and effectiveness based on their policies and preferences.

As outlined in the comparison in Section 4, AHP can provide decision makers with a robust solution. The most important part of this method is that, this method puts decision maker's preference in the first place and helps to select a method for their decision making in maintenance management without considering uncertainty rate and problem complexity. This can lead industries and decision makers to select a method while their preferences are the priority for making their decisions. Nowadays making decisions in maintenance management plays an important role to improve efficiency in productivity and optimizing the maintenance budget. Selecting the best decision making method was always a critical aspect of the process. Problem complexity, uncertainty rate, outranking methods, data type and decision maker preference are the main points which must be considered during selecting decision making methods.

On the other hand, ELECTRE family methods can be a good option for decision makers who want to consider all alternatives and prefer to outrank the alternatives instead of eliminating them. This method is not suitable for cases that alternatives are widely different so expressing preferences are almost impossible as they are not comparable in those cases.

It must be considered that the above developed criteria can differ by looking into the decision making methods from different aspects of maintenance management. Decision making for different aspect of reliability centered maintenance and Decision making for outsourcing options for different aspect of maintenance management e.g. outsourcing spare parts and outsourcing total maintenance activities and can be possible future work.

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