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Comparison of Multi Criteria Decision Making Methods From The Maintenance Alternative Selection Perspective

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ABSTRACT

The significance of decision making from the maintenance perspective has long been acknowledged by the manufacturing industry. Appropriate maintenance alternative decision making increases machine reliability and enhances both productivity and product quality. By contrast, poor decision making disrupts production and increases production costs. Thus, different multi-criteria decision making (MCDM) methods were developed and implemented in the maintenance alternative decision making process. This paper reviewed and compared the application of four popular MCDM techniques in maintenance decision making. The methods included analytic hierarchy process, elimination and choice expressing reality, simple additive weighting, and technique for order preference by similarity to ideal solution. The comparisons were based on the aspects of consistency, problem structure, concept, core process, and accuracy of final results.

KEYWORDS: *Decision making, Maintenance alternative, Multi criteria Decision Making*

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I. INTRODUCTION

Maintenance has emerged since the construction of physical structures such as ships and machines. In general, maintenance is defined as the combination of all technical and administrative actions, including supervision and action intended to retain the machine or restore it to a state in which it can perform a required function [1]. Effective maintenance ultimately aims to determine suitable actions that can keep machine performance at acceptable levels and extend the life cycle of the machine. Different types of maintenance alternatives have been proposed to achieve the ultimate goal. However, a maintenance policy implemented in a similar machine but in different manufacturing environments may not produce similar results because of various operating factors such as humidity, temperature, and work load [2]. In addition, decision making in maintenance selection is often accompanied by diverse constraints and limitations from social, environmental, and economic perspectives [3]. Examples of these constraints include operator safety issues, government regulation, resource limitation, and budget. Consequently, the selection of a suitable maintenance policy becomes a crucial decision-making process to obtain high levels of success for the firm beneficiaries [4] in manufacturing industries.

The need to choose a suitable maintenance policy has led to the development of numerous multi-criteria decision-making (MCDM) approaches. This study examines the four most widely used MCDM methods in maintenance alternative decision making: analytic hierarchy process (AHP), elimination and choice expressing reality (ELECTRE), simple additive weighting (SAW), and technique for order preference by similarity to ideal solution (TOPSIS). The benefits and limitations of each alternative are identified to assist decision makers in choosing the suitable MCDM technique. The rest of the paper is organized as follows: Section 2 provides a general classification of maintenance alternatives. Section 3 presents an overview of decision making in maintenance. The application of MCDM methods in maintenance alternative is described in Section 4. Section 5 reveals the findings regarding the MCDM methods reviewed in the previous section. Finally, Section 6 concludes the paper.

II. MAINTENANCE ALTERNATIVES CLASSIFICATION

The concept of maintenance is continuously developed to sustain the evolution of the manufacturing industry. Figure 1 presents the five main types of maintenance policies: corrective maintenance, preventive maintenance, predictive maintenance, autonomous maintenance, and design out maintenance.

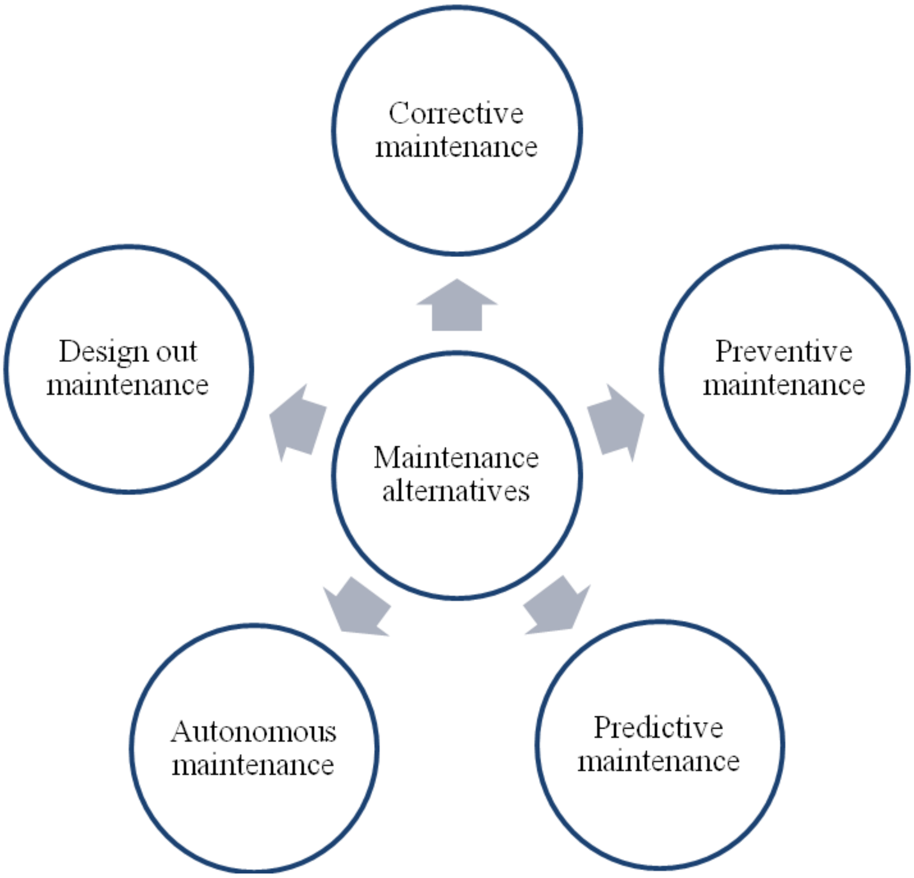

Figure 1: Types of maintenance alternatives

Traditionally, the original maintenance alternative implemented in the industry is corrective maintenance (CM) [5]. CM or failure-based maintenance corresponds to actions employed when functionality fails. CM is a well accepted alternative because it only needs to be performed when a machine breaks down. However, machines have become more complex, which leads to an increased probability of failure over time. Consequently, the traditional role of CM, which is generally viewed as a fire-fighting approach, can no longer ensure that the needs of modern manufacturing industries are met. At the same time, machine failure entails a massive amount of capital for component replacement or ominous situations that require machine replacement. Sudden stoppage of a production line incur waste in production or reduced utilization in addition to demanding emergency attendance to restore the machine, considering that actions are only performed when machines break down,. However, CM remains useful when machine malfunction does not affect the overall performance of the machine (e.g., insignificant machines).The use of CM is not economical in certain cases. Thus, another maintenance policy, preventive maintenance (PM), has started drawing interest. PM is conducted as scheduled to ensure smooth manufacturing and machine functionality [6]. For instance, PM can be performed every 80 hours on a machine operating eight hours a day, indicating that the machine will be shut down for PM every 10 days. Despite possible production and process interruptions due to PM, the machine remains in functioning condition. Such maintenance reduces the risk of unexpected machine failures [7]. Another maintenance alternative is predictive maintenance (PdM), which is also known as a condition-based maintenance. PdM is suitable for highly sophisticated machines operated by complex and demanding replaceable components that may deteriorate upon prolonged use [8]. PdM addresses significant mechanical deterioration by changes in component parameters, which may lead to a major machine breakdown. Indication parameters can be divided into operating and environmental parameters. Operating parameters include operating temperature and pressure, whereas environmental parameters include ambient temperature, humidity, radiation, lubricant temperature, and dirt surrounding the machine. Autonomous maintenance (AM) is also known as a detection-based maintenance policy. This policy is the latest maintenance policy developed among the existing policies [9]. AM combines maintenance and production to accomplish maintenance tasks [10]. AM suggesting that maintenance tasks are not the sole responsibility of the maintenance department but are duties shared with operator in-charge of the machines. In AM, operators are trained and educated to gain adequate skills and knowledge for accomplishing a simple preventive work. The goal is to maintain the machine effectively and efficiently [11]. For example, operators are assigned to perform simple tasks such as cleaning up scraps or lubricating components to lengthen their lifespan.

Design out maintenance (DOM), another prevalent maintenance policy is basically used to facilitate maintenance or reduce the need for maintenance by modifying machine components. DOM is usually implemented when problems continue to occur despite the application of other maintenance policies. Imperative factors to consider in DOM include reliability, modularity, standardization, and ergonomics of the components and the machine.The adoption of maintenance alternative can vary from one machine to another or within the industry. Therefore, an optimal decision can only be reached in the presence of a systematic and visibly distinct decision-making approach. The adopted approach can verify and assess the respective characteristics and criteria of maintenance alternatives weighed against industry requirements and limitations.

III. OVERVIEW OF MAINTENANCE ALTERNATIVES SELECTION

Decision making is encountered when an optimal maintenance alternative has to be chosen from a pool of maintenance alternatives. Regardless of the area of application, a good decision can only be reached when the processes are systematically structured and clearly defined [12]. Figure 2 summarizes the five steps of maintenance alternative decision making.

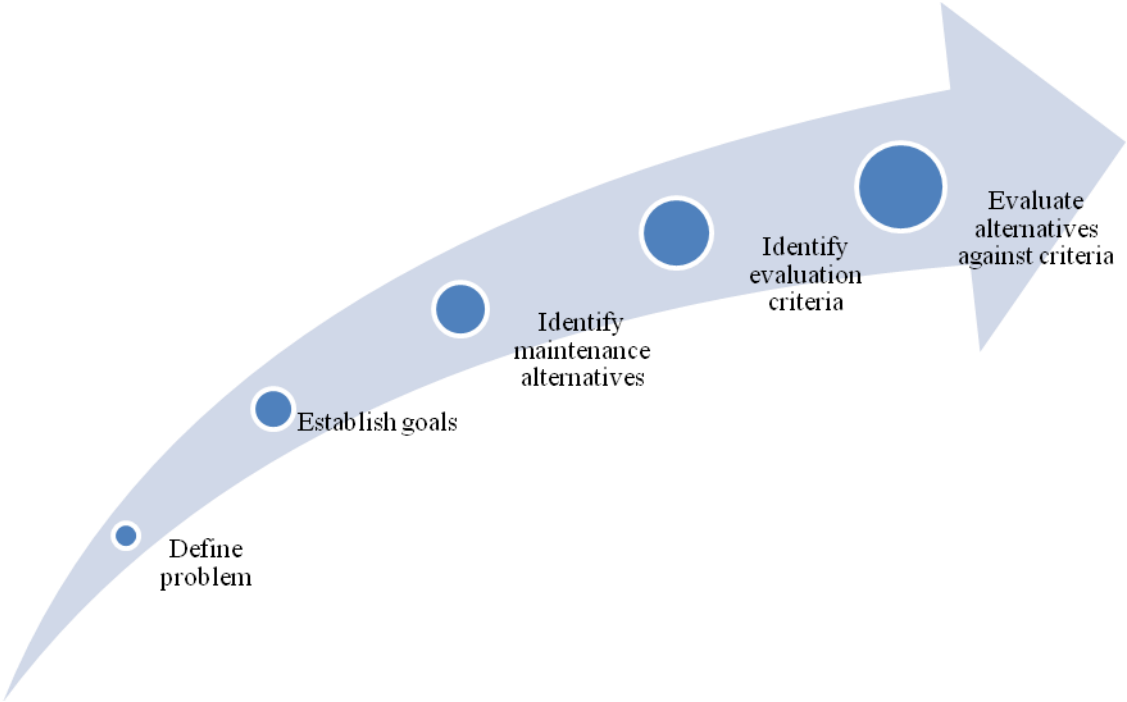

Figure 2: Maintenance alternative decision making

The first step under the maintenance alternative decision making process is problem definition, as shown in Figure 2. The gap between the actual situation and the desired situation is defined with the consent of the decision makers once the problem has been identified. This step requires expressing the issue clearly and precisely to obtain a comprehensible outcome for the subsequent steps. Goals can be established when a problem is clearly defined. According to [13], a goal can be defined as a specific aspiration that decision makers seek to achieve. A goal is a broad statement expressed positively to provide the desired direction of a problem. One example of a goal is the reduction of machine failure rates with minimal maintenance costs. The potential maintenance alternatives that can be selected to change an existing condition into a desired condition are identified in the third step. Alternatives that fail to meet this requirement are excluded, and the remaining maintenance alternatives are evaluated. Prior to feasibility evaluation of the maintenance alternatives, the criteria have to be determined. The rules and standards that guide decision making are also determined. The criteria identified are used to measure the achievement relative to the goal [14]. Thus, the criteria listed must be able to discriminate effectively the alternatives to simplify the selection. Finally, the maintenance alternative can be evaluated against the criteria to select the optimal maintenance alternative by preferable multiple criteria decision-making methods. Among the processes involved in decision making, the MCDM method used to evaluate maintenance alternatives against the criteria significantly affects the final results because each MCDM method has a distinct operating algorithm. The evaluation principle found in maintenance alternative decision making, including AHP, ELECTRE, SAW, and TOPSIS is introduced.

3.1. AHP

Developed by Thomas Saaty in the 1970s, AHP allows the structuring of a problem into hierarchies and then evaluates the components by pairwise comparison [15]. A problem is decomposed into elements and then structured into a linear hierarchy to a finite level. Goals are usually designated in the upper level of the hierarchy, whereas criteria and sub-criteria are in the intermediate level. Alternatives are at the lowest level of the criteria. Pairwise comparison with a scale factor of one to nine is conducted for all criteria and alternatives. The weights of the criteria are determined, and all local sets of weights are combined to obtain the global weights for all alternatives. The matrix of the pairwise comparisons of the *n* criteria *C* at a given level can be expressed as

$$D = \begin{bmatrix} C_1/C_1 & C_1/C_2 & \cdots & C_1/C_n \\ C_2/C_1 & C_2/C_2 & \cdots & C_2/C_n \\ \vdots & \vdots & \ddots & \vdots \\ C_n/C_1 & C_n/C_2 & \cdots & C_n/C_n \end{bmatrix} \quad (1)$$

3.2. ELECTRE

ELECTRE is widely studied and has evolved into ELECTRE I, II, III, IV, and TRI [16]. This technique also uses pairwise comparison by using concordance and discordance indexes. The concordance index indicates that alternative A is better than alternative B in terms of sum of weights. A discordance index represents the absolute difference of the alternative pair divided by the maximum difference over all pairs. The global concordance index C_{ik}, which shows that the value supporting the concordance among all criteria under the hypothesis that A_i outranks A_k, can be defined as follows:

$$C_{ik} = \sum_{j=1}^{m} W_j c_j(A_i A_k) \,/\, \sum_{j=1}^{m} W_j, \quad (2)$$

where W_i is the weight related to the j_{th} criterion. Outranking can be performed to determine the outranking relation among alternatives by setting a threshold value for the indexes [17].

3.3. SAW

Developed by MacCrimon in 1968, SAW is also known as the weighted linear combination, scoring method, or weighted sums [18]. SAW uses the principle of weighted average. The method is very simple in which a scaled value is given for each alternative by an attribute. Scaled values are then multiplied by their respective weight assigned by the decision maker, as shown in Equation (3).

$$A_j = Max \sum_{i=1}^{j} a_{ij} w_j, \quad (3)$$

where A_j is the alternative score, a_{ij} is the actual value of the i_{th} alternative with respect to the j_{th} criterion, and w_j is the weight of the j_{th} criterion. The result sums up the total obtained values and the criterion weight, and the highest score is considered the best alternative [19].

3.4. TOPSIS

TOPSIS was first introduced by Yoon and Hwang in the 1980s [20]. TOPSIS applies a simple concept of maximizing distance from the negative-ideal solution and minimizing the distance from the positive ideal solution [21]. The chosen alternative must be as close as possible to the ideal solution and as far as possible from the negative-ideal solution. The ideal solution represents the maximal benefit solution determined from a composite of best performance values shown in the matrix. The negative-ideal solution represents the minimal benefit solution, which is also the composite of the worst values in the matrix. Proximity of alternatives to the ideal solution S_i^* and the negative-ideal solutions S_i^- can be obtained using the square root of squared distances in the imaginary attribute space given in Equations (4) and (5).

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2} \quad (4)$$

Similarly, the separation from the negative-ideal solution $A^-$is given in Equation (5):

$$S_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^-)^2} \qquad (5)$$

where v_{ij} represents the value of the i_{th} alternative corresponding to the j_{th} criterion; v_j* and v_j^- are the ideal positive- and negative-ideal values of the j_{th} criterion, respectively. The most preferable alternative is nearest to the ideal solution and farthest from the negative-ideal solution. The computing algorithm proposed by each MCDM method varies according to the operating concept. AHP attempts to divide the problem into different hierarchy levels before justifying the most suitable solution, whereas ELECTREE attempts to justify the preference on the basis of concordance and discordance indexes. SAW has occupied the weighted average principle as its core concept in decision making. Lastly, TOPSIS presents an idea of distance-based decision making. Despite the differences in the operating concepts, these MCDM methods have greatly contributed to the effectiveness of decision making from the maintenance perspective.

3.5.Application of MCDM In Maintenance Alternatives Selection

Acknowledging the importance of maintenance function in the manufacturing industry that has drastically increased the application of MCDM in decision making, the following section discusses the adoption of this method for identifying an optimal maintenance policy. MCDM can enhance the effectiveness of decision making by structuring the analytical process systematically and mathematically; this aspect is usually lacking in actual decision making. AHP is one of the most common decision-making techniques. [22] used AHP in selecting the optimal maintenance alternative for an integrated gasification combined cycle plant. With the complexity of the process considered, the case study is left with six of the most important criteria: safety, equipment, failure frequency, downtime length, and operating conditions. In this case, machines are divided into three main categories based on the consequences of failure. The outcome of the study showed that predictive maintenance facilitates Group 1. Group 2 reveals a slight preference for opportunistic maintenance, whereas preventive maintenance and corrective maintenance suit Group 3. [23] used AHP in maintenance alternative selection for a thermal power plant by using four criteria: safety, added value, cost, and feasibility. The result showed that PM is the most suitable alternative. [24] adopted AHP to identify the optimal maintenance alternative for a machine used in virtual learning aimed at increasing reliability and availability levels. In addition, [25] also used AHP to decompose an optimal maintenance alternative selection problem in the textile industry. The problem was structured into four levels, with four criteria in the second level, and further decomposed into eight sub-criteria in the third level. AHP is used to scale the weight for each criterion. The outcome of the AHP method is further continued using TOPSIS to rank the alternatives. [26] also used AHP to determine a suitable maintenance alternative for a wind turbine machine by taking implications of cooperative alliances into consideration during decision making process. Under similar circumstances, [27] suggested the use of AHP to measure health, safety, environment awareness, and cost issues during maintenance alternative decision making in the oil and gas industries. [28] adopted AHP to select the most practical maintenance alternative for machines with different operational functions in the oil refinery industry.

Several studies related to maintenance alternative decision making by using ELECTRE and SAW have been conducted, although they are seldom reported compared with those on AHP. [29] proposed the ELECTRE to determine a suitable maintenance alternative for improving the reliability and availability of a compressor. Five different criteria were used during the evaluation to justify the most applicable maintenance alternative: safety, cost, added value, applicability, and information available. In the case study presented by [16], high failure rates in machines on shop floors producing automotive components seriously affected the production rate and did not meet the production demand. Thus, the authors adopted ELECTRE in the selection of the most suitable machining tools for the production of computer numerical control machine automotive components by using various criteria such as maintainability, cost, availability of spare parts, and performance. [30] used SAW to rank the maintenance alternatives for a rolling-element bearing in the paper mill industry. The maintenance alternatives are evaluated based on their ability to provide relevant information such that failures are prevented and machines are used optimally. [31] used SAW to determine the most preferable maintenance alternatives that can achieve the goal determined by company management. Maintenance alternatives are evaluated according to safety, cost, added value, and feasibility. However, a hypothetical example is used to illustrate the proposed methodology.

Recently, TOPSIS also started gaining popularity in maintenance alternative decision making. [25] used TOPSIS to select maintenance alternative in the textile industry. In this case, TOPSIS is used to compensate precision ranking by pairwise comparison. The criteria used in the case study consist of environmental conditions, component failure, training required, and flexibility of the maintenance alternative.

The distance of the alternatives from the positive-ideal solution and the negative-ideal solution are computed and compared. TOPSIS was also used by [32] to determine the optimal maintenance alternative feasible for a company while ensuring the quality of the presented product without a substantial increase in maintenance cost. [33] also used TOPSIS to select an alternative that can increase maintenance efficiency in Electrofan Company according to criteria based on financial, social, and environmental aspects, among others.

IV. CONCLUSION

As reviewed in the previous section, four MCDM methods with different operating principles have been applied to select the optimal maintenance policy. This section presents the comparison of these methods in terms of concept, core process, consistency, and problem structure, which are discussed in subsequent sections.

4.1. CONCEPT

AHP, ELECTRE, SAW, and TOPSIS allow tradeoffs between attributes; that is, one attribute can be offset by opposing changes in other attributes. However, every method uses a different concept in this tradeoff. AHP and SAW focus on a model from which a vector of global scores is obtained by competing alternatives. ELECTRE is under the concordance model, in which preference ranking is arranged to provide concordance measures. TOPSIS is classified under compromising models, with the notion that no ideal solution exists, but a solution with optimal values on all attributes is simultaneously selected [34].

4.2. CORE PROCESS

Core process is the principle calculation of each MCDM method, which has its unique solution algorithm. AHP uses the hierarchy principle and pairwise comparison matrices to select the obtained alternative rankings [35], whereas ELECTRE focuses on the principle of pairwise comparison by using concordance and discordance indexes. SAW applies the principle of weighted average by assigning a scale value to each alternative, whereas TOPSIS calculates the shortest distance of an alternative from the positive ideal solution and the longest distance from the negative-ideal solution [17].

4.3. CONSISTENCY

AHP provides consistency in judgment considering that the consistency index is calculated before creating pairwise comparison matrices. For instance, when alternative A is preferred to B and B is preferred to C, then alternative C is preferred by AHP principle, thereby ensuring consistency. ELECTRE can also provide consistency through threshold values created through indexes [21]. However, TOPSIS and SAW cannot provide controlled consistency because they have no comparative indexes as indicators.

4.4. PROBLEM STRUCTURE

Decision making can become easier than usual if the correct MCDM method is selected for various selection problems. The problem structure includes the number of criteria used and the number of alternatives to be selected in a decision-making problem. AHP uses a hierarchical structure by pairwise comparison; hence, this method becomes complicated for a problem structure with a number of alternatives or criteria because the number of comparisons increases. ELECTRE is based on one-way fuzzy logic, regardless of the number of criteria or alternatives [36]. TOPSIS and SAW can solve the selection problem; however, the process provides numerous alternatives and criteria because of the simple mathematical calculations involved.

4.5. FINAL OUTCOME

The final outcomes indicate the final ranking of the alternatives undergoing the selection process using different MCDM methods. Net ranking is obtained in AHP, TOPSIS, and SAW among all alternatives after the MCDM steps are completed. In ELECTRE, partial ranking is obtained because of the comparison of the concordance and discordance threshold indexes. These concepts allow the special comparison of the aforementioned aspects because of the principle behind different MCDM methods. In addition, the comparison of concepts suggests how the method is applied. Each method provides a rough calculation algorithm during MCDM. Consistency in judgment is also ensured throughout the selection considering that decision makers change their preferences at different times. Moreover, in real-world selection problems, the number of criteria and alternatives can be large, thus rendering the selection problem complex. This condition is especially true when certain solution algorithms such as pairwise comparison are applied. Therefore, the final ranking of the alternatives may vary for the same selection problem because of different solution algorithms used in different methods. Consequently, the overall characteristic of the final result obtained using the different MCDM method needs to be compared. The methods are compared in terms of four aspects, as presented in Table 1.

Table 1: Comparison of AHP, ELECTRE, SAW and TOPSIS

	AHP	ELECTREE	SAW	TOPSIS
Consistency	Yes	Yes	No	No
Core process	Hierarchy principle	Pairwise comparison principle	Weighted average principle	Distance principle
Problem structure	Few criteria and alternatives	Many criteria	Many criteria and alternatives	Many criteria and alternatives
Concept	Scoring model	Concordance model	Scoring model	Compromising model
Final results	Global, net ordering	Partial pre-order	Global, net ordering	Global, net ordering

As indicated in Table 1, AHP and ELECTRE show a controlled consistency, unlike SAW and TOPSIS. However, TOPSIS is not inferior to either AHP or ELECTRE because TOPSIS uses a compromising idea in which an optimal solution is the optimum among all attributes. Thus, no arguments regarding consistency arises because every alternative is compared with the ideal solution in the algorithm. AHP is clearly inferior to ELECTRE, SAW, and TOPSIS in terms of problem structure because AHP cannot be used when numerous criteria and alternatives are involved. In terms of the final result, ELECTRE is inferior to the rest because it provides only partial pre-ordering, which leads to a further investigation of the results to obtain the final ranking for every alternative. Among all methods, TOPSIS is suitable for large-scale data and relatively simple. TOPSIS is applicable when large numbers of alternatives and criteria are involved because the TOPSIS algorithm is direct and causes no complication in calculation despite the large-scale data. Therefore, calculation using the TOPSIS principle is easy to perform and implement. TOPSIS can also yield a final result in a net ordering format, with precise relative closeness to the ideal solution. On the basis of the final ranking, comparison of the final score of each alternative is thus allowed, so that decision making can be more flexible. TOPSIS also exhibits the ability of simultaneously considering various criteria with different units [37]. This method can be used regardless of the criteria unit as long as the necessary data are crisp numbers.

V. CONCLUSION

This paper presented a comparison of four MCDM methods used in maintenance decision making in terms of consistency, core process problem structure, concept, and final results**.** TOPSIS exhibited the highest potential in maintenance decision analysis. These comparison results can also be used as reference data for maintenance management to determine suitable approaches to decision analysis. Appropriate decision analysis methods can obtain accurate results with minimal investment and effort.

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