

Research Article

Integrating Fuzzy AHP and Fuzzy TOPSIS Models for Construction Equipment Maintenance Strategy Selection

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Abstract

Maintenance is the combination of all technical, administrative, and managerial actions during the life cycle of an item intended to retain it in, or restore it to a state in which it can perform the required function under normal stated operating conditions. Maintenance management is a crucial element that governs the economic value of the organization itself. Maintenance costs constitute a major part of the total operating costs of all construction equipment. Currently, industries are facing a lot of challenges encountered due to the continually evolving world of technologies, and environmental and safety requirements. Thus, the study was focused on Integrating Fuzzy AHP and Fuzzy TOPSIS Models for Construction Equipment Maintenance Strategy Selection. The evaluation was a multiple-criteria decision-making problem. The fuzzy AHP and fuzzy TOPSIS methods were used as an evaluation tool. To achieve the objective, the data were collected from primary and secondary source of data collection. The method of data analysis for this study was made by integrated methodology, and the analysis was made by using Microsoft Excel. The study revealed that skill development, production waste, product quality, health and safety training, and facilities are important criteria. The finding revealed that preventive maintenance and time-based maintenance were the best maintenance strategies.

Keywords

Fuzzy AHP, Fuzzy TOPSIS, Construction Equipment, and Maintenance Strategy

1. Introduction

Maintenance is the combination of all technical, administrative, and managerial actions during the life cycle of an item intended to retain it in or restore it to a state in which it can perform the required function under normal stated operating conditions. Currently, industries are facing a lot of challenges such as optimization of operation and maintenance due to the continually evolving world of technologies, competitiveness among themselves in the globalization era, and environmental and safety requirements [1]. To maintain their competitiveness capability in the market, higher productivity with minimum production cost becomes the

main target [2]. The concern towards total quality and profitability of an organization are crucial factors in the business. Industrial maintenance has gained high recognition over the last few decades in various industries. Consequently, over the years, many different strategies have been developed to support maintenance management implementation in the industry [1]. With increasing automation and mechanization, production processes in the industry are becoming highly sensitive to equipment and people. Either productivity or production cost, cannot be apart from maintenance issues.

The cost of maintenance is rising due to fast changes in

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maintenance strategies and resources, forcing the organization to consider proactive maintenance management to encounter maintenance issues, not just for a cost-saving measure [3]. Maintenance management is a crucial element that governs the economic value of the organization itself. Maintenance costs constitute a major part of the total operating costs of all construction equipment [4]. The most significant gap identified from this study was the implications of maintenance action in the construction equipment were rare, especially in Ethiopia. Even studies on maintenance strategy in practice show that some managers are unaware of the different types of maintenance strategies and selection methods. According to [5] lack of appropriate maintenance culture and awareness made it even worse where the maintenance activities were only implemented during the emergency, and no priority was given to encountering the maintenance issues. Hence it results in the deterioration of the equipment, and it may be more difficult to deliver the quality of service that users have come to expect and to meet the requirements of the construction companies. The costs of operating and maintaining these wastewater systems will increase as the assets age, and the community may be faced with excessive costs that it can no longer afford. Moreover, the absence of a properly implemented maintenance program leads to premature equipment failure, potential cost overruns, and increased crew idle time due to the equipment awaiting repairs. As a consequence, the quality of maintenance management is a significant factor affecting actual construction equipment ownership costs. Implementation of a detailed maintenance program can consistently lower the cost of operating the equipment contemplated in the estimate.

Thus, the objectives of the study focused on integrating fuzzy AHP and fuzzy TOPSIS models for construction equipment maintenance strategy selection. To achieve the objective of the study, there is a need to identify the most important criteria and the alternative maintenance strategies in the recent literature. The combined methodologies of fuzzy AHP and fuzzy TOPSIS model provide a novel and extended contribution to previous studies by considering their impotence, subjectivity, and uncertainties taken into account through the fuzzy set theory in a fuzzy environment for increasing the validity and reliability of the study.

The motivation for this work is the existing need for some technical methodologies for optimum selection of the most fit maintenance strategies. In this research, two of the common methods for decision-making, namely the Analytical Hierarchy Process (AHP), and a fuzzy Technique for Order Performance by Similarity to Ideal Solution are used for the selection of the best maintenance strategy. The two methods are simple but powerful in making decisions at different business and functional levels under highly complex and uncertain conditions. The proposed approach is examined in the maintenance strategy selection of the construction equipment. In this study, the eight strategies of maintenance are compared according to six criteria of added value,

applicability, equipment process control, safety, cost, and effectiveness, and the best combination of maintenance strategies for a group of equipment is determined.

The remainder of this paper is organized as follows. Section 2 describes the Construction Equipment Maintenance Strategy Selection Criteria, and Equipment Maintenance Strategies. Section 3 describes fuzzy decision-making methodology, Section 4 presents numerical data analysis. Section 5 shows discussions, managerial implications, and limitations. Finally, general conclusions and remarks are then presented in Section 6.

2. Literature Review

Maintenance management is the management of all assets owned by a company, based on maximizing the return on investment in the asset [6]. Another approach [6] indicates how a maintenance system can be seen as a simple input-output system. The inputs are the manpower, management, tools, equipment, etc., and the output is the equipment configured well and working reliably to reach the planned plant operation.

Maintenance is required for equipment because the efficiency and quality of production are reduced over time and the machines may fail more often. Therefore a technical system that is in regular condition for a long time, i.e. to function regularly over a longer period of time, is necessary to be properly maintained [7]. Further, the role of equipment maintenance plays an important role in keeping availability and reliability levels, controlling quality, quantity, and safety requirements, and reducing costs is more evident and important than ever [1]. Therefore, keeping any kind of equipment or component in working order to prevent failures so as to perform its intended function, ensuring safety, as well as protecting the environment, appropriate maintenance of equipment is a must [2]. Maintenance is not just ensuring the healthiness of equipment in a facility but it also plays a crucial role in achieving the organization's goals and objectives with optimum maintenance cost and maximum production.

Traditionally, maintenance management dealt with short-term issues like resources, cost, manpower, etc. Recent past, maintenance management has changed its concerns towards the consideration of long-term goals like competition, sustainability, and strategy. Therefore, maintenance management needs to be viewed from a strategic perspective. The cost associated with the maintenance has increased constantly over the decades. In the present scenario, depending on the type of industry, about 15-70 percent of production costs are attributed to maintenance and hence are central to most cost reduction programs [1].

Thus, selecting the right maintenance strategy is essential for construction equipment by considering various factors to ensure the efficiency, cost-effectiveness, and reliability of equipment. Here are discussed briefly as follows.

2.1. Maintenance Strategy Selection Criteria

The selection of the most appropriate maintenance strategy is an important problem that an organization is dealing with. A proper maintenance strategy, applied to equipment will save money for the organization. Many of the goals dealing with the selection of the best maintenance strategy for equipment in an organization are non-monetary or intangible, which besides the monetary goals makes the selection problem more complex in maintenance management and the output of maintenance is hard to measure and quantify [3].

Selecting the right maintenance strategy is crucial for ensuring the reliability and efficiency of equipment and systems. Here are some key criteria to consider when choosing a maintenance strategy.

2.1.1. Added Value

Value added in manufacturing is the sum of gross output less the value of intermediate inputs used in production for industries [8].

Product quality: refers to how well a product meets customer needs, serves its intended purpose, and adheres to industry standards.

Production waste: - Industrial waste is a key factor when assessing the sustainability of a manufacturing process or company [9].

Profit:- Profit describes the financial benefit realized when revenue generated from a business activity exceeds the expenses, costs, and taxes involved in sustaining the equipment activity while it is an operation.

Delivery time:- Delivery of equipment, supplies, and/or services must be made no later than the time stated in the contract, or within a reasonable period of time if a specific time is not stated. Delivery of equipment shall be made to the Project site during normal working hours.

2.1.2. Applicability

Applicability “relates to the extent to which the results are likely to impact on practice”. Applicability means that something is capable of being applied, relevant, or appropriate for a certain construction company [10].

Technology:- the application of scientific knowledge on the machinery and equipment for practical purposes, especially in industry to reduce the industry's ability to spend money on new technology.

Skill development: Skill development refers to the process of improving specific skills to be more efficient and effective when performing a task, and acquiring knowledge, competencies, and abilities through life experiences, study, or training [11].

Growth innovation:- Innovation is the practical implementation of ideas that result in the introduction of new goods or services or improvement in offering goods or services [12].

Technique feasibility:- Technical feasibility is the

evaluation of the prospective implementation and development of a proposed equipment product or project from a technical point of view [13].

Reliability:- is the probability of equipment failure in a given time under set conditions, and the measure of time that a piece of equipment will correctly function without failure [14].

Availability:- The probability that an item will operate satisfactorily at a given point in time when used under stated conditions in an ideal support environment [13].

Utilization:- measures how efficiently businesses use machinery, vehicles, heavy equipment, and other assets [15].

Redundancy:- is a reliability engineering technique that involves running multiple machines in parallel to provide availability even when one machine fails, and using identical pieces of equipment to ensure continuous operation or improve performance [16].

2.1.3. Equipment Process Control

Equipment process control refers to devices and systems used in manufacturing to monitor and manage production processes using sensors, data monitoring, and specialized industrial control systems to regulate flow, output, mixture, and other aspects of continuous production processes [12].

Spare part inventories:- refers to the stock of replaceable or service parts kept on hand by businesses for uninterrupted operations, maintenance, and repairs. It is separate from the main inventory and is used to minimize downtime and optimize costs.

Level of service:- define the asset's performance targets in relation to reliability, quantity, quality, responsiveness, safety, capacity, environmental impacts, comfort, affordability, and legislative compliance.

Criticality of Machine:- A criticality rating given to a piece of equipment is used to determine how often the equipment should be inspected or maintained, as well as to give a scheduler a guide as to which notifications and work orders can be rescheduled to a future date, and which require more immediate attention.

Life Cycle Costing:- Equipment Life Cycle Costing is a method used to assess the total cost of owning and operating equipment over its entire lifespan [17].

Long-term Funding Strategy: is a collaborative process that combines financial forecasting with strategizing. The fundamental principle of long-term finances is to finance the strategic capital projects of the company or to expand the company's business operations [17].

2.1.4. Safety

Machine safety refers to the measures and precautions taken to protect individuals from hazards posed by machines and equipment. It involves safeguarding workers from exposure to potential mechanical hazards, such as moving machinery and equipment parts:

Facilities: construction machinery, and tangible equipment

that support an organization.

Health and safety training: is crucial for ensuring a safe working environment. It involves educating employees on how to identify, prevent, and mitigate workplace hazards.

Personnel safety: involves ensuring the safety of individuals in the workplace. This includes managing workplace conditions, addressing injuries, and minimizing risks and hazards.

Environment: refers to all the physical elements that make up a place, from the ground up.

2.1.5. Cost

Equipment cost refers to the asset valuation method that applies to equipment including all expenses associated with the acquisition of the equipment as well as those needed to ready it for use by the company.

Production cost: refers to the expenses a company incurs from manufacturing a product or providing a service that generates revenue [18].

Consultation: a meeting in which someone talks to a person about construction-related problems and discussion about something that is being decided regarding their operation, and maintenance of facilities.

Spare parts cost: The cost of spare parts can vary widely depending on the type of part and the equipment or vehicle it is for.

Specialist employee: is defined as the capability to produce goods and services to achieve the goals of the organization [19].

Hardware and software: Equipment hardware refers to the physical components of equipment or any machinery used for specific tasks, and equipment software focuses on operating systems, application software like word processors, and programming software.

Effectiveness

Effectiveness is a key performance indicator as a general indicator for identifying performance losses used to measure the equipment productivity in a manufacturing system [18].

Efficiency: is to evaluate how well a machine performs its designed task in terms of quantity and/or quality of performance.

Productivity: equipment productivity is a measure of the overall effectiveness of organization systems in utilizing its resource and capital to convert into useful output, and is not a measure of the capabilities of labor alone [20].

Customer satisfaction: refers to how well the equipment meets or exceeds the expectations and needs of the customers who use it in terms of performance, reliability, ease of use, and value for money.

Maintainability: is the ease with which a product can be maintained to correct defects or their cause, repair or replace faulty or worn-out components without having to replace still working parts, and prevent unexpected working conditions.

Reparability: is a measure of the degree to and ease with which a product can be repaired and maintained, usually by

end consumers. Repairable products are put in contrast to obsolescence or products designed with planned obsolescence.

Conformity: is testing or other activities that determine whether a process, product, or service complies with the requirements of a specification, technical standard, contract, or regulation.

Functionality: Functionality is the quality or state of being functional, that is, having a practical use or purpose for which something is designed.

2.2. Maintenance strategies

Maintenance includes all activities required to keep an asset at maximum operating condition. The activities are usually carried out according to a certain maintenance strategy. The maintenance strategies may have developed accordingly with the development of manufacturing systems [21]. In the early days, maintenance had been mainly concentrated around corrective maintenance. Today, maintenance management becomes a complex function, encompassing technical and management skills, while still requiring flexibility to cope with the dynamic business environment. Maintenance strategies have gradually changed from preventive maintenance (PM) (including condition-based maintenance (CBM) and time-based maintenance (TBM) to design-out maintenance (DOM) and total productive maintenance (TPM) [21].

2.2.1. Corrective Maintenance

Corrective maintenance is a conventional maintenance strategy that appeared early in the industry. It has been employed in maintenance operations due to a knowledge shortage of equipment failure behaviors. Corrective maintenance can be carried out immediately or deferred by appropriate maintenance technicians who are contracted to assess the situation and fix the repairs [21]. Corrective maintenance is the remedial action performed because of failure or deficiencies found during preventive maintenance or otherwise, to repair an item to its operating state [22].

2.2.2. Time-Based Maintenance

Time-based maintenance (TbM) is a preventive maintenance strategy that involves performing routine maintenance tasks on an asset at fixed time intervals, regardless of its condition. It is a scheduled preventive measure that aims to prevent failures before they happen and improve asset performance. TBM maintenance is planned maintenance, as it must be scheduled in advance [21].

2.2.3. Preventive Maintenance

Preventive maintenance is a proactive strategy that involves regularly scheduled maintenance activities. Its purpose is to prevent unexpected failures in the future and

ensure optimal equipment health for longer durations [23].

2.2.4. Total Predictive Maintenance

Predictive maintenance extends automated condition monitoring by a computerized evaluation of the input data and allows intelligent prognostics to detect precursors of failure and to predict how much time remains before the likely occurrence of a failure [23].

The strategy aims to predict system failures and prevent them by constantly monitoring and analyzing various parameters. Predictive maintenance determines exactly when it's the best time to perform equipment maintenance using data collected from IoT devices such as sensors, machine learning, and real-time equipment monitoring [24].

2.2.5. Condition Based Maintenance

Condition-based maintenance (CBM) is a preventive maintenance strategy that relies on monitoring assets or equipment to determine when maintenance work is necessary. It involves the use of sensors and other monitoring equipment to collect data on the performance of equipment. CBM is a proactive technique that focuses on real-time asset performance and alerts employees when equipment is performing outside of its specified range [24].

2.2.6. Opportunistic Maintenance

Opportunistic maintenance is a form of preventive maintenance that takes advantage of unplanned or planned system shutdowns to conveniently replace equipment items or components using available maintenance resources. It involves systematic and proactive management of existing opportunities to maximize their potential and long-term viability [22].

2.2.7. Routine Maintenance

Routine maintenance refers to maintenance tasks that are done on a planned and ongoing basis to identify and prevent problems before they result in equipment failure. Routine maintenance is the regular maintenance a company performs to keep assets in good operating condition and reduce unexpected breakdowns. These tasks are carried out regularly to identify and address issues before they lead to equipment failure [22].

2.2.8. Reliability Centered Maintenance

Reliability Centered Maintenance (RCM) is an engineering framework that focuses on optimizing the reliability of a system or process by identifying potential failure modes and ways to prevent them before they occur. Reliability Centered Maintenance is used to develop the minimum preventive maintenance tasks necessary to ensure that an equipment item or system meets its inherent reliability requirement at minimum cost [25].

2.3. Fuzzy AHP and Fuzzy TOPSIS Approaches for Construction Equipment Maintenance Strategy Selection

2.3.1. Fuzzy AHP Approaches for Construction Equipment Maintenance Strategy Selection

We briefly review the rationale of fuzzy theory before the development of fuzzy AHP, and fuzzy TOPSIS.

AHP and Fuzzy Set Theory are two decision-making methodologies used to solve different types of problems. AHP is used for multi-criteria decision-making, while Fuzzy Set Theory is used for problems involving uncertainty and imprecision. The Fuzzy Analytic Hierarchy Process (FAHP) is an expanded version of the Analytic Hierarchy Process (AHP) that allows for the use of fuzzy sets and linguistic terms in decision-making [26].

The fuzzy Analytic Hierarchy Process (F-AHP) embeds the fuzzy theory to the basic Analytic Hierarchy Process (AHP), which was developed by Saaty [27]. To deal with the vagueness of human thought, Zadeh [28] first introduced the fuzzy set theory, which was oriented to the rationality of uncertainty due to imprecision or vagueness. AHP Fuzzy Set Theory is a combination of these two methodologies that is used when a decision-making problem involves multiple criteria that are subjective and uncertain [29].

Fuzzy Set Theory is used to model the subjective and uncertain aspects of the problem. To do this, the weights of the criteria and sub-criteria are represented by membership functions that define the degree of membership of each element in a set. These membership functions can be defined based on linguistic terms provided by decision-makers, such as "absolutely preferred" or "not preferred" [30].

A fuzzy set $A = \{(x, \mu_A(x)) / x \in X\}$, is a set of ordered pairs and X is a subset of the real numbers R , where $\mu_A(x)$ is called the membership function which assigns to each object " x " a grade of membership ranging from zero to one [30]. If the membership value is 1, it is the full element of the set; if it is 0, it is not the element of the set. In contrast to classical sets, the membership degrees of the elements can vary in infinite numbers between the range of $[0, 1]$ in fuzzy sets [31].

1) Membership Function

The membership function of \tilde{A} fuzzy set is shown by $\mu_{\tilde{A}}(x)$. Fuzzy sets described each object with the membership function having a degree of membership ranging between 0 and 1 [31]. If x element belongs to \tilde{A} fuzzy set, it is $\mu_{\tilde{A}}(x) = 1$; if it does not belong, it is $\mu_{\tilde{A}}(x) = 0$ [31].

2) Verbal /linguistic variables

In fuzzy logic, verbal/linguistic variables are an important concept of fuzzy sets. Linguistic variables are used to express human feelings and decisions [31]. The value of linguistic variables in natural languages is not numbers but words or sentences, and decision-making with words or sentences is easier than decision-making with numbers [31].

3) Fuzzy numbers

Fuzzy numbers are a fuzzy subset of real numbers. Fuzzy numbers are used to handle the indefinite numerical values such as around 7 or close to 10 [30]. Triangular Fuzzy Number is utilized in the pairwise comparison process to describe subjective judgments in Fuzzy AHP. The TFN is determined by three real numbers consisting of "M" = {l, m, u}. The parameters l, m, and u signify the smallest possible value, the most promising value, and the largest value that describes each fuzzy event [32].

The membership function of a triangular fuzzy number (TFN) A, is a function $\mu_A(x): \mathbb{R} \rightarrow [0, 1]$, defined as [33].

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x < l \\ \frac{x-l}{m-l}, & l \leq x \leq m \\ \frac{u-x}{u-m}, & m \leq x \leq u \\ 0, & x > u \end{cases} \quad (1)$$

Where, inequality $l \leq m \leq u$ holds, Variables l, m, and u are the lower, middle, and upper values, respectively, and when $l = m = u$, TFN becomes a crisp number.

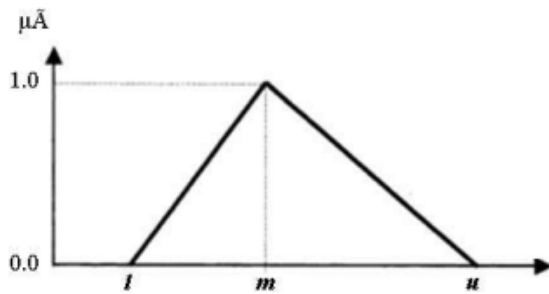


Figure 1. The membership function of the triangular fuzzy number [31].

The TFN can be denoted by $\tilde{A} = (l, m, u)$. Assume two TFNs, $\tilde{A}_1 = (l_1, m_1, u_1)$ and $\tilde{A}_2 = (l_2, m_2, u_2)$ and scalar $k > 0$, $k \in \mathbb{R}$. The basic arithmetic operations (addition, subtraction, multiplication, scalar multiplication, and inverse element) are respectively defined as follows [31].

Addition of the fuzzy number \oplus [31].

$$\tilde{A}_1 \oplus \tilde{A}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (2)$$

Multiplication of the fuzzy number \otimes [31].

$$\tilde{A}_1 \otimes \tilde{A}_2 = (l_1 * l_2, m_1 * m_2, u_1 * u_2), \text{ for } l_1, l_2 > 0; m_1, m_2 > 0; u_1, u_2 > 0 \quad (3)$$

Subtraction of the fuzzy number \ominus [31].

$$\tilde{A}_1 \ominus \tilde{A}_2 = (l_1 - l_2, m_1 - m_2, u_1 - u_2) \quad (4)$$

Division of a fuzzy number \oslash [31].

$$\tilde{A}_1 \oslash \tilde{A}_2 = (l_1 / m_2, m_1 / m_2, u_1 / l_2), \text{ for } l_1, l_2 > 0; m_1, m_2 > 0; u_1, u_2 > 0 \quad (5)$$

Reciprocal of the fuzzy number [34]

$$\tilde{A}^{-1} = (l_1, m_1, u_1)^{-1} = (1/u_1, 1/m_1, 1/l_1), \text{ for } l_1, l_2 > 0; m_1, m_2 > 0; u_1, u_2 > 0 \quad (6)$$

2.3.2. Fuzzy TOPSIS Approaches for Construction Equipment Maintenance Strategy Selection

The method is based on the concept that the chosen alternative should have the shortest distance from the positive-ideal solution (i.e., achieving the minimal gaps in each criterion) and the longest distance from the negative-ideal solution (i.e., achieving the maximal levels in each criterion). TOPSIS defines an index called similarity to the positive-ideal solution and the remoteness from the negative-ideal solution. Then, the method chooses an alternative with the maximum similarity to the positive-ideal solution [34]. The merit of using a fuzzy approach is to assign the relative importance of attributes using fuzzy numbers instead of precise numbers for suiting the real world in a fuzzy environment. This section extends the TOPSIS to the fuzzy environment [35]. This method is particularly suitable for solving the group decision-making problem under a fuzzy environment. In the multi-criteria decision-making models choosing an alternative, the overall goal depends on two or more criteria [34]. According to [36] decision-making problem is the process of finding the best option from all of the feasible alternatives. The decision-making problem can be concisely expressed in matrix format:

$$D = \begin{matrix} & \begin{matrix} C_1 & C_2 & \dots & C_n \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ A_3 \\ \dots \\ A_m \end{matrix} & \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ x_{31} & x_{32} & \dots & x_{3n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \end{matrix} \quad (7)$$

$$W = [w_1, w_2, w_3, \dots, w_n] \quad (8)$$

Where,

$A_1, A_2, A_3, \dots, A_m$ is possible alternatives among which decision-makers have to choose, C_1, C_2, \dots, C_n is the criteria with which alternative performance is measured, x_{ij} is the rating of alternative A_i concerning criterion C_j and w_j is the weight of criterion C_j .

3. Fuzzy Decision-Making Methodology

Decision-making is a process of identifying and choosing alternatives based on the values and preferences of the decision-maker [37]. The study can employ a multi-method approach, encompassing quantitative and qualitative research to obtain information for the objective of the study. Quantitative approaches were carried out by questionnaire survey, whereas qualitative research was done by

interviewing key informants. In this paper, a total of 15 decision experts were chosen as the target population.

The sample size that can be used for this study was consensus-based MCDM methods called Experts Panel MCDM methods. According to [38] the number of experts used for carrying out MCDM methods was based on their subject knowledge, experience, skill, and personal contacts. For this study, convenience sampling was adopted, because it focuses on representative samples that are willing, and readily available for the study. Primary data were collected from a

questionnaire survey, interviewing key informants whereas secondary data were collected from the literature review were used to collect all the relevant data to answer the research questions. The decision Experts involved in the survey were invited to fill out a questionnaire and had several years of experience which was selected based on based on their subject knowledge, experience, and skill.

The overall framework and steps of the newly proposed methodology was carried out by integration of fuzzy AHP and fuzzy TOPSIS are shown in Figure 2.

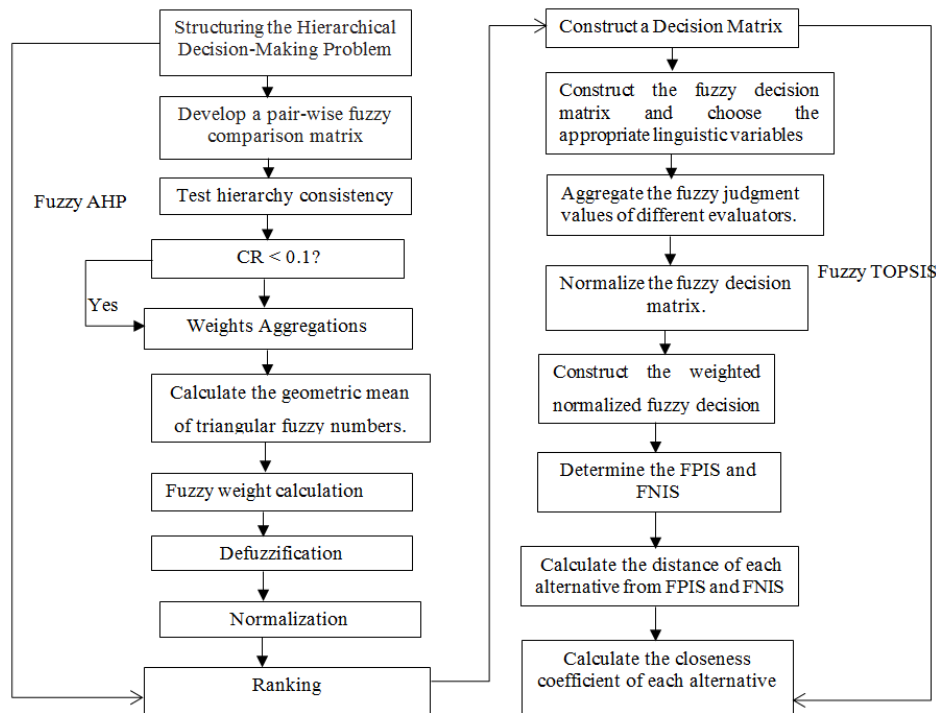


Figure 2. The steps, and procedures conducted by the applied methodologies.

The fuzzy AHP and fuzzy TOPSIS approaches are the two fuzzy decision-making analysis methods used in this study to evaluate and select the appropriate construction equipment maintenance strategy. Furthermore, the construction equipment companies considered were ranked according to their maintenance strategy, as described in the following subsections.

3.1. Fuzzy AHP Decision-Making Methods

This study employs fuzzy AHP to fuzzy hierarchical analysis by allowing fuzzy numbers for pairwise comparisons and finds the fuzzy preference weights. In this section, we briefly review concepts for fuzzy hierarchical evaluation. Then, the following steps will introduce the computational process of the fuzzy AHP technique in detail [37].

1) Structuring the Hierarchical Decision-Making Problem

In the first step, the hierarchical decision-making problem

is structured. This step is similar to that in the conventional AHP approach [30]. The structures of the analytic hierarchy process were established by identifying six variable groups and their associated sub-criteria (a total of 32 variables). Each expert was asked to evaluate the six dimensions and confirm their mutual independence to reduce the relevance of the decision variables for qualifying the premise assumption of FAHP. The structure is built “from the top with the goal of the decision from a broad perspective, through the intermediate levels (variables) to the lowest level (which is usually a set of the sub-variables).”

2) Develop a pair-wise fuzzy comparison matrix.

The pair-wise comparison judgments are represented by fuzzy triangular numbers denoted by $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$. As in the conventional AHP, $n(n-1)/2$ K, experts (decision-makers) are required for each comparison group for a level to construct a positive fuzzy reciprocal comparison matrix $\tilde{A} = \{\tilde{a}_{ij}\}$. They determine the important dimensions by pair-wise comparison

matrices among all the criteria of the hierarchical structure as Eq. (9) matrix (\tilde{A}): The matrix is expressed as follows [30].

$$\tilde{A} = \{\tilde{a}_{ij}\} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \dots & \tilde{a}_{2n} \\ \tilde{a}_{31} & \tilde{a}_{32} & \dots & \tilde{a}_{3n} \\ \vdots & \vdots & \dots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \dots & \tilde{a}_{2n} \\ 1/\tilde{a}_{13} & 1/\tilde{a}_{23} & \dots & \tilde{a}_{3n} \\ \vdots & \vdots & \dots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \dots & 1 \end{bmatrix} \quad (9)$$

Where,

$$\tilde{a}_{ij} = \begin{cases} \tilde{1}, \tilde{3}, \tilde{5}, \tilde{7}, \tilde{9} & \text{The variable } i \text{ is relative preferred to variable } j \\ 1 & \forall i = j \quad \text{Variable } i \text{ is equally preferred to variable } j \\ \tilde{1}^{-1}, \tilde{3}^{-1}, \tilde{5}^{-1}, \tilde{7}^{-1}, \tilde{9}^{-1} & \text{The variable } i \text{ is relatively less preferred than variable } j \end{cases}$$

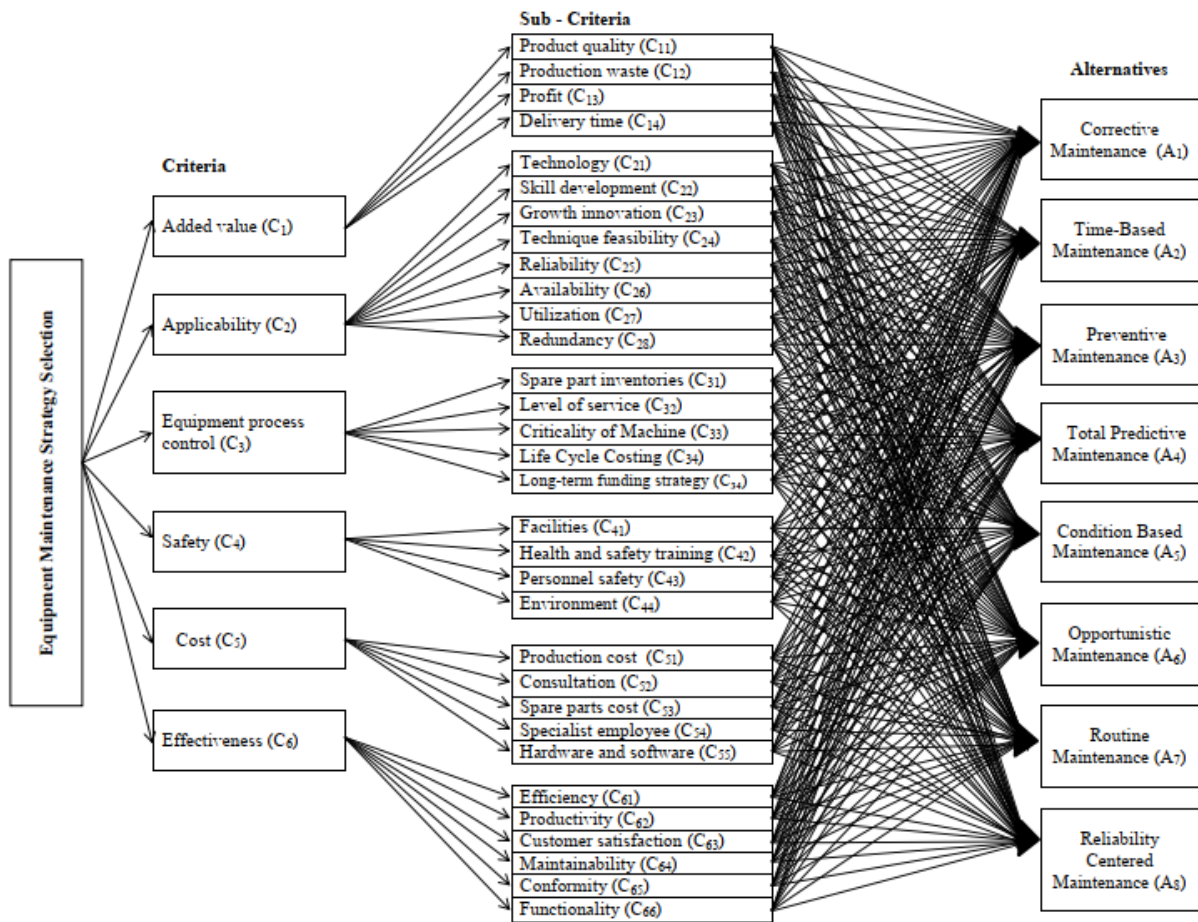


Figure 3. Hierarchical Structure of AHP Model.

Table 1. Linguistic terms and the corresponding triangular fuzzy numbers [39].

Saaty scale	Linguistic Variable	Fuzzy Number	Triangular Fuzzy Scale	Reverse Triangular Fuzzy Number
1	Equally preferred (EP)	$\tilde{1}$	(1, 1, 3)	$(\frac{1}{3}, \frac{1}{1}, \frac{1}{1})$
3	Moderate preferred (MP)	$\tilde{3}$	(1, 3, 5)	$(\frac{1}{5}, \frac{1}{3}, \frac{1}{1})$

Saaty scale	Linguistic Variable	Fuzzy Number	Triangular Fuzzy Scale	Reverse Triangular Fuzzy Number
5	Strong preferred (SP)	$\tilde{5}$	(3, 5, 7)	$(\frac{1}{7}, \frac{1}{5}, \frac{1}{3})$
7	Very strong preferred (VSP)	$\tilde{7}$	(5, 7, 9)	$(\frac{1}{9}, \frac{1}{7}, \frac{1}{5})$
9	Absolute preferred (AP)	$\tilde{9}$	(7, 9, 9)	$(\frac{1}{9}, \frac{1}{9}, \frac{1}{7})$

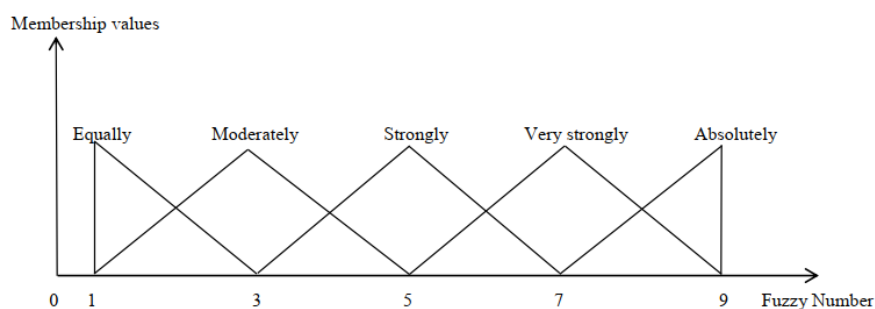


Figure 4. Linguistic variables for the importance weight of each criterion [40].

Once the number of the decisions of the experts (decision-makers) was determined the experts were then asked to perform pair-wise comparisons between the

dimension and the compared dimension. The questionnaire is developed based on the criteria and level with a conventional AHP questionnaire format recommended by Saaty [36].

Table 2. The questionnaire survey was designed with a pairwise comparison format with linguistic variables [40].

Evaluation of Dimension										
Dimension	Positive					Negative				Compared Dimension
	AP	VSP	SP	MP	EP	NMP	NSP	NVSP	NAP	
V ₁										V ₂
----										----
V ₁										V ₆
V ₂										V ₃
----										----
V ₂										V ₆
V ₃										V ₄
V ₃										V ₅
V ₃										V ₆
V ₄										V ₅
V ₅										V ₆

Where, (EP) Equally preferred, (MP) Moderately preferred, (SP) strongly preferred, (VSP) Very strongly preferred, (AP) Absolute preferred, (EP) Equally preferred, (NMP) Not moderately preferred, (NSP) Not strongly preferred, (NVSP) Not very strongly preferred, and (NAP) Not absolutely preferred.

Table 3. Linguistic variables describe the weights of the criteria and values of ratings [41].

Linguistic Variable	Fuzzy numbers	Membership function	Domain	Triangular Fuzzy Scale (l, m, u)
Just equal	$\tilde{1}$	1	1	(1, 1, 1)
Equally preferred		$\mu(A)(x) = (3-x) / (3-1)$	$1 \leq x \leq 3$	(1, 1, 3)
Moderately preferred	$\tilde{3}$	$\mu(A)(x) = (x-1) / (3-1)$ $\mu(A)(x) = (5-x) / (5-3)$	$1 \leq x \leq 3$ $3 \leq x \leq 5$	(1, 3, 5)
Strongly preferred	$\tilde{5}$	$\mu(A)(x) = (x-3) / (5-3)$ $\mu(A)(x) = (7-x) / (7-5)$	$3 \leq x \leq 5$ $5 \leq x \leq 7$	(3, 5, 7)
Very strongly preferred	$\tilde{7}$	$\mu(A)(x) = (x-5) / (7-5)$ $\mu(A)(x) = (9-x) / (9-7)$	$5 \leq x \leq 7$ $7 \leq x \leq 9$	(5, 7, 9)
Absolutely preferred	$\tilde{9}$	$\mu(A)(x) = (x-7) / (9-7)$	$7 \leq x \leq 9$	(7, 9, 9)

3) Test hierarchy consistency

The pairwise comparison in AHP is given by the expert opinion; this opinion could be or could not be consistent. AHP develops a consistency measure, by using a consistency ratio that is calculated using the consistency index, CI, and random index, RI. Eigenvalue λ and eigenvector value are used to determine the consistency index [32].

$$CI = \frac{\lambda_{\max} - n}{(n-1)} \quad (10)$$

Where λ_{\max} the maximum eigenvalue, and n is the dimension of the judgment matrix.

RI is obtained by averaging the CI of a randomly generated reciprocal matrix.

Where: n is the number of items compared

Table 4. Random consistency index [27].

Matrix Dimension	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

If CR, the ratio of CI and RI is less than 10%, then the evaluations of the decision maker can be considered as having an acceptable consistency, the calculated consistency ratio should be less than or equal to 0.1. CR value with >10% has resulted in inconsistency of judgments within that matrix. This suggests that the evaluation process needs to be reviewed and improved [32]. In AHP Once all pair-wise comparisons are conducted and are confirmed to be consistent, the judgments can be synthesized to find the priority ranking of each criterion and its attributes by using the eigenvector and eigenvalue [32].

$$CR = \frac{CI}{RI} \quad (11)$$

Where CR is the consistency ratio RI is the random index

4) Weights Aggregations

According to [40], if there is more than one decision maker, the preferences of each decision maker of alternatives, and the final priorities of the alternatives can be obtained by aggregating the local priorities of elements of different levels, which are obtained in the above steps. The AHP approach adopts an additive aggregation Eq. (12) with normalization of the sum of the local priorities to unity.

The opinions of experts were transferred into triangular fuzzy numbers by using the following formula [42].

$$\tilde{a}_{ij} = (\tilde{a}_{ij}^1 \otimes \tilde{a}_{ij}^2 \otimes \tilde{a}_{ij}^3 \dots \dots \otimes \tilde{a}_{ij}^N)^{1/n} \quad (12)$$

$$\tilde{a}_{ij} = (\tilde{a}_{ij}^1 \otimes \tilde{a}_{ij}^2 \otimes \tilde{a}_{ij}^3 \dots \dots \otimes \tilde{a}_{ij}^{15})^{1/15}$$

Where, \tilde{a}_{ij} - is the integrated triangle fuzzy number by N experts.

\tilde{a}_{ij}^k - is the i-th to the j-th variable pair comparison by expert k.

\otimes - is the symbol of matrix multiplication.

5) Calculate the geometric mean of triangular fuzzy numbers

According to Buckley [40], the geometric mean of the triangular fuzzy numbers values of each criterion is calculated as shown in Eq. (13). Here \tilde{r}_i still represents triangular values.

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \tilde{a}_{i3} \otimes \dots \otimes \tilde{a}_{in})^{1/n} \quad [34] \quad (13)$$

6) Calculate the fuzzy weight of variables.

The fuzzy weights of each criterion can be found in Eq. (14), by incorporating the next 3 sub-steps [43].

1. Find the vector summation of each \tilde{r}_i
2. Find the (-1) power of the summation vector. Replace the fuzzy triangular number, to make an increasing order.
3. To find the fuzzy weight of criterion i (\tilde{w}_i), multiply each \tilde{r}_i with this reverse vector.

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \tilde{r}_3 \oplus \dots \oplus \tilde{r}_n)^{-1} \quad [34] \quad (14)$$

Where \tilde{a}_{in} is the fuzzy comparison value of variable i to variable n

\tilde{r}_i is the geometric mean of the fuzzy comparison value of variable i to each variable,

\tilde{w}_i is the fuzzy weight of the i-th variables, which can be indicated by a triangular fuzzy number.

\oplus is the symbol of matrix plus

Hence $\tilde{w}_i = (Lw_i, Mw_i, Uw_i)$. Lw_i , Mw_i , and Uw_i stand for the lower, middle, and upper values of the fuzzy weight of the i-th variables respectively.

7) Defuzzification

The defuzzification phase starts with the weighted vector \tilde{w}_i , since \tilde{w}_i are still fuzzy triangular numbers they need to be de-fuzzified to obtain the total integral value for the TFNs by the center of area method proposed by [27], via applying Eq. (15).

$$BNP_i = \frac{[(Uw_i - Lw_i) + (Mw_i - Lw_i)]}{3} + Lw_i \quad (15)$$

8) Normalize weights to make sure the sum of weights add-up to 1

Remember the sum of the factors must add up to one. If they are not adding up, then we have to normalize them to make sure they are adding up to one. In the normalization phase, the normalized weight vectors w_i for criteria are obtained [40].

$$BNPw1 = \frac{BNP1}{(BNP1 + BNP2 + \dots + BNPn)} \quad (16)$$

9) Ranking

The weights for each sub-criterion are obtained by

multiplying the weights of the criteria and sub-criteria. Then, arranging the obtained weights, the sub-criteria ranking is received [33].

3.2. Fuzzy Technique for Order Preference by Similarity to Ideal Solution Method

In this study, we propose this method to evaluate and select the appropriate equipment maintenance strategy for construction companies. TOPSIS views a MADM problem with m alternatives as a geometric system with m points in the n-dimensional space of criteria [44].

Among many famous MCDM methods, the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) is a practical and useful technique for ranking and selecting a number of possible alternatives by measuring Euclidean distances. TOPSIS method contains a solution process consisting of 9 steps. The steps for implementing the fuzzy TOPSIS methodology are given below [45].

1) Construct a Decision Matrix

Assume there m alternatives (maintenance strategy) A_i ($i = 1, 2, \dots, m$) to be evaluated against n selection criteria C_j ($j = 1, 2, \dots, n$). Subjective assessments are to be made by DM to determine (a) the weighting vector $W = (w_1, w_2, \dots, w_j, \dots, w_n)$ and (b) the decision matrix $X = \{x_{ij}, i = 1, 2, \dots, m; j = 1, 2, \dots, n\}$, using the linguistic terms given in Table 1. The weighting vector W represents the relative importance of n selection criteria C_j ($j = 1, 2, \dots, n$) for the problem. The decision matrix $X = \{x_{ij}, i = 1, 2, \dots, m; j = 1, 2, \dots, n\}$ represents the ratings of alternative A_i with respect to selection criteria C_j . Given the weighting vector W and decision matrix X , the objective of the problem is to rank all the alternatives by giving each of them an overall strategy with respect to all selection criteria. The decision matrix can be expressed as follows:

$$A = \begin{matrix} & \begin{matrix} C_1 & C_2 & \dots & C_n \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ A_3 \\ \dots \\ A_m \end{matrix} & \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ x_{31} & x_{32} & \dots & x_{3n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \end{matrix} \quad (17)$$

$$W = [w_1, w_2, w_3 \dots \dots \dots w_n], \quad (18)$$

Where,

$A_1, A_2, A_3 \dots \dots \dots A_m$ is possible alternatives among which decision-makers have to choose, $C_1, C_2, \dots \dots \dots C_n$ is the criteria with which alternative performance is measured, x_{ij} is the rating of alternative A_i concerning criterion C_j and w_j is the weight of criterion C_j .

2) Construct the fuzzy decision matrix and choose the appropriate linguistic variables for the alternatives to the criteria. The experts have their range for the linguistic variables employed in this study according to

their subjective judgments.

Table 5. Linguistic terms and their numerical intervals for fuzzy TOPSIS [37].

Attribute Grade	Fuzzy Linguistic Terms for Decision-Making	Triangular Fuzzy Number
1	Very Low Important	(1, 2, 3)
2	Low Important	(2, 3, 4)
3	Medium Low	
4	Medium Important	(3, 4, 5)
5	Medium High	
6	Highly Important	(4, 5, 6)
7	Very high Important	(5, 7, 9)

- 3) Aggregate the fuzzy judgment values of different evaluators regarding the same evaluation dimensions to get the aggregated fuzzy rating X_{ij} of alternative A_i under criterion C_j [46].

$$X_{ij} = \frac{1}{K}(X_{ij}^1 + X_{ij}^2 + X_{ij}^3 + \dots + X_{ij}^K)$$

Where, X_{ij} is the rating of alternative A_i with respect to criterion C_j evaluated by K expert and

$$X_{ij}^K = (l_{ij}, m_{ij}, u_{ij})$$

- 4) Obtain the decision matrix to identify the j^{th} criteria with respect to the alternative.

$$R = [r_{ij}]_{m \times n} \quad (19)$$

$$i = 1, 2, \dots, m; j = 1, 2, \dots, n$$

- 5) Normalize the fuzzy decision matrix

Normalize the decision matrix in order to make each criterion value is limited between 0 and 1, so that each criterion is comparable. The initial data with respect to each criterion will be normalized by dividing the sum of criterion values. For fuzzy data denoted by triangular fuzzy numbers as (l_{ij}, m_{ij}, u_{ij}) , the normalized values for benefit-related criteria and cost-related criteria are calculated as follows:

$$\tilde{r}_{ij} = \left\{ \left(\frac{l_{ij}}{u_{ij}^+}, \frac{m_{ij}}{u_{ij}^+}, \frac{u_{ij}}{u_{ij}^+} \right) \right\}, j \in B \quad (20)$$

$$\tilde{r}_{ij} = \left\{ \left(\frac{l_{ij}}{u_{ij}^-}, \frac{m_{ij}}{u_{ij}^-}, \frac{u_{ij}}{u_{ij}^-} \right) \right\}, j \in C \quad (21)$$

$$u_j^+ = \max_i C_{ij} \text{ if } i \in B$$

$$l_j^- = \min_i l_{ij} \text{ if } i \in C$$

- 6) Construct the weighted normalized fuzzy decision matrix.

The weighted fuzzy normalized decision matrix is shown as following matrix \tilde{V} :

$$\tilde{V} = [\tilde{v}_{ij}]_{m \times n}, i = 1, 2, \dots, m; j = 1, 2, \dots, n \quad (22)$$

Where $\tilde{v}_{ij} = \tilde{r}_{ij} \otimes \tilde{w}_j$, \otimes = Fuzzy multiplication

- 7) Determine the fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS).

According to the weighted normalized fuzzy decision matrix, the elements \tilde{v}_{ij} are normalized positive triangular fuzzy numbers, and their ranges belong to the closed interval $[0, 1]$. Then, it can define the Fuzzy Positive Ideal Solution (FPIS, A^+) and Fuzzy Negative Ideal Solution (FNIS, A^-) as the following formula:

$$A^+ = (\tilde{v}_1^+, \tilde{v}_2^+, \tilde{v}_3^+ \dots \dots \dots \tilde{v}_n^+) \quad (23)$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \tilde{v}_3^- \dots \dots \dots \tilde{v}_n^-) \quad (24)$$

Where, $\tilde{v}_j^+ = (1, 1, 1)$ and $\tilde{v}_j^- = (0, 0, 0)$, $j = 1, 2, \dots, n$

- 8) Calculate the distance of each alternative from FPIS and FNIS.

The distance (d_i^+ and d_i^-) of each alternative from A^+ and A^- can be calculated as:

$$d_i^+ = \sum_{j=1}^n d(\tilde{v}_{ij}, \tilde{v}_j^+), i = 1, 2, \dots, m; j = 1, 2, \dots, n \quad (25)$$

$$d_i^- = \sum_{j=1}^n d(\tilde{v}_{ij}, \tilde{v}_j^-), i = 1, 2, \dots, m; j = 1, 2, \dots, n \quad (26)$$

Where, d (d_i^+ , d_i^-) is the distance measurement between two fuzzy numerical values

Let $\tilde{a} = (a_1, a_2, a_3)$ and $\tilde{b} = (b_1, b_2, b_3)$ be two triangular Fuzzy numbers.

If $\tilde{a} = \tilde{b}$ then $a_i = b_i \forall i = 1, 2, 3$.

If \tilde{a} is a triangular fuzzy number and $a_1 > 0$ and $a_u \leq 1$ for A fuzzy set $\tilde{a} \in [0, 1]$, then \tilde{a} is called a normalized positive triangular fuzzy number.

Let $\tilde{a} = (a_1, a_2, a_3)$ and $\tilde{b} = (b_1, b_2, b_3)$ be two triangular Fuzzy numbers. The distance between them is given using the vertex method by [46]:

$$d(\tilde{a}, \tilde{b}) = \sqrt{1/3 ((a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2)} \quad (27)$$

- 9) Calculate the closeness coefficient of each alternative.

The CC_i is defined to determine the ranking order of all alternatives once the d_i^+ and d_i^- of each alternative have been calculated and rank each CC of each alternative in descending order. The alternative with the highest CC value will be the best choice. Calculate similarities to ideal solutions. This step solves the similarities to an ideal solution by the formula:

$$CC_i = \frac{d_i^-}{d_i^- + d_i^+}, i = 1, 2, \dots, m \quad (28)$$

4. Numerical Data Analysis

4.1. Experts Panel Selection

In performing the FAHP methodologies first an expert panel was selected based on their credentials and expertise in relevant domains for conducting pairwise comparisons for evaluating a set of variables. The information provided by the expert panel is presented in Table 6, and their interpretations

of their profile are presented in percentages as follows.

The percentage value of the surveyed stakeholders for this study was 26.67% are clients, 46.67% are contractors, and 26.67% are consultants. Regarding the educational level of the respondents, 100.00% were MSc. and above. Among the participants 73.33% of the respondents were male, and 26.67% of the respondents were female. As to the working experience of the respondents, 33.33% were between 6-10 years, 66.67% of the respondents were more than 15 years.

Table 6. The expert panel's demographics.

Parameter	Frequency	Percentage (%)	Parameter	Frequency	Percentage (%)
Type of organization			Gender		
Clients	4	26.67%	Male	11	73.33%
Contractors	7	46.67%	Female	4	26.67%
Consultants	4	26.67%	Work experience of respondents		
Educational level			6-10 years	5	33.33%
MSc. and above	15	100.00%	> 15 years	10	66.67%

4.2. Results of Fuzzy Analytic Hierarchy Process Methodology

1) Structuring the Hierarchical Decision-Making Problem

In the first step of this study, the author decomposes and structures a complex decision problem. The decision hierarchy has been constructed by breaking a decision problem into smaller sub-problems, and the problem becomes more manageable.

The hierarchical decision-making problem by considering the main variable groups and input variables identified from the literature as the schematic structure depicted (see Figure 3). Its ultimate goal is to evaluate and select the best equipment maintenance management strategy which is placed in the first level in the hierarchical structure based on the pairwise comparison. The six variable groups and thirty-three input variables are located in the second and third levels, respectively.

2) Develop a pair-wise fuzzy comparison matrix.

The data obtained from questionnaires were transformed into linguistic terms fuzzy numbers using Table 1. The importance comparison for each criterion was performed via a questionnaire. The pairwise comparison matrix of the group and sub-criteria evaluated by the decision experts was presented in Tables (8-14).

3) Test hierarchy consistency

In this study, the consistency ratio is employed to check the consistency of the expert preferences. When the value of $CR \leq$

10% indicates a good level of consistency in the comparative judgments represented in that matrix it is acceptable. CR value greater than 10% has resulted in the inconsistency of judgments within that matrix.

As an illustration, a fuzzy pairwise comparison matrix of the criteria with respect to the objective can be calculated as follows.

$$\lambda_{\max} = 6.352, n = 6,$$

$$RI_{(n=6)} = 1.24$$

Therefore, the CI can be determined by using Eq. (10), and the CR by using Eq. (11), of the pairwise judgmental matrix can be calculated as follows: $CI = 0.070$.

$$CR = \frac{0.070}{1.12} = 0.056 < 0.1$$

Thus, the judgmental matrix is acceptable.

The consistency ratios of all other matrices are less than 10%. Thus, all the judgments are consistent.

4) Weights Aggregations

After checking the validation of the expert's opinion, the geometric mean method aggregates the preference of the overall decision experts in relation to the objective with a triangular fuzzy number by using Eq. (12).

$$\tilde{a}_{ij} = (\tilde{a}_{ij}^1 \otimes \tilde{a}_{ij}^2 \otimes \tilde{a}_{ij}^3 \dots \dots \otimes \tilde{a}_{ij}^N)^{1/15}$$

As a sample calculation, the aggregated fuzzy pairwise comparison values for the criteria with respect to the goal are shown in the following matrix \tilde{A} .

Table 7. The aggregated fuzzy pairwise comparison values for the criteria with respect to the goal.

	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆
C ₁	1.000, 1.000, 1.000	0.302, 0.412, 0.712	2.132, 2.987, 3.757	1.304, 1.864, 2.453	2.629, 3.518, 4.438	0.565, 0.720, 0.928
C ₂	1.335, 2.430, 3.483	1.000, 1.000, 1.000	4.328, 5.426, 6.489	2.130, 3.028, 4.058	4.434, 5.528, 6.499	0.857, 1.162, 1.505
C ₃	0.259, 0.322, 0.438	0.159, 0.192, 0.248	1.000, 1.000, 1.000	0.253, 0.316, 0.423	1.252, 1.864, 2.781	0.430, 0.603, 0.890
C ₄	0.376, 0.486, 0.677	0.246, 0.330, 0.470	2.268, 3.078, 3.870	1.000, 1.000, 1.000	1.550, 2.502, 3.537	1.048, 1.552, 2.192
C ₅	0.225, 0.284, 0.380	0.154, 0.181, 0.226	0.360, 0.536, 0.799	0.269, 0.373, 0.578	1.000, 1.000, 1.000	0.780, 1.030, 1.380
C ₆	1.122, 1.463, 1.896	0.664, 0.860, 1.167	1.123, 1.659, 2.325	0.456, 0.644, 0.954	0.725, 0.971, 1.282	1.000, 1.000, 1.000

5) Geometric Mean Calculation of Triangular Fuzzy Numbers

The geometric mean of the fuzzy comparison values was found using the Fuzzy Analytic Hierarchy Process (FAHP) and Microsoft Excel for each criterion. Using Eq. (13), the geometric mean for criteria 1 was calculated as follows:

$$\tilde{r}_1 = ((1 \otimes 0.302 \otimes 2.132 \otimes 1.304 \otimes 2.629 \otimes 0.565)^{1/6}, (1 \otimes 0.412 \otimes 2.987 \otimes 1.864 \otimes 3.518 \otimes 0.720)^{1/6}, (1 \otimes 0.712 \otimes 3.757 \otimes 2.453 \otimes 4.438 \otimes 0.928)^{1/6})$$

$$\tilde{r}_1 = (1.032, 1.285, 1.602)$$

With similar steps, other calculations of the geometric means of fuzzy comparison values for each criterion are determined. It also includes the total values, the inverse values, and the values in increasing order.

$$\tilde{r}_2 = (1.732, 2.209, 2.641)$$

$$\tilde{r}_3 = (0.477, 0.579, 0.733)$$

$$\tilde{r}_4 = (0.858, 1.098, 1.380)$$

$$\tilde{r}_5 = (0.428, 0.522, 0.660)$$

$$\tilde{r}_6 = (0.832, 1.039, 1.300)$$

6) Fuzzy Weight Calculation

The fuzzy preference weights are calculated, and the results are presented below after fuzzy weights for each criterion were computed using Eq. (14) as follows:

$$\tilde{w}_1 = \tilde{r}_1 \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \tilde{r}_3 \oplus \tilde{r}_4 \oplus \tilde{r}_5 \oplus \tilde{r}_6)^{-1}$$

Where \tilde{r}_i was multiplied by the inverse of the summation vector in the form of increasing order.

$$\tilde{w}_1 = (1.032, 1.285, 1.602) \otimes \left(\frac{1}{1.602 + \dots + 1.300} \right), \left(\frac{1}{1.285 + \dots + 1.039} \right), \left(\frac{1}{1.032 + \dots + 0.832} \right)$$

$$\tilde{w}_1 = (0.124, 0.191, 0.299)$$

Likewise, the residual fuzzy weights \tilde{w}_i values are:

$$\tilde{w}_2 = 0.208, 0.328, 0.493$$

$$\tilde{w}_3 = 0.057, 0.086, 0.137$$

$$\tilde{w}_4 = 0.103, 0.163, 0.258$$

$$\tilde{w}_5 = 0.051, 0.078, 0.123$$

$$\tilde{w}_6 = 0.100, 0.154, 0.243$$

Table 8. Fuzzy weights of the main criteria with respect to the goal.

Main Criteria	Fuzzy Weights			BNP	Crisp weight (BNPw)	Rank
Added value (C1)	0.124	0.191	0.299	0.205	0.192	2
Applicability (C2)	0.208	0.328	0.493	0.343	0.322	1
Equipment process control (C3)	0.057	0.086	0.137	0.093	0.088	5
Safety (C4)	0.103	0.163	0.258	0.175	0.164	3
Cost (C5)	0.051	0.078	0.123	0.084	0.079	6
Effectiveness (C6)	0.100	0.154	0.243	0.166	0.156	4

Table 9. Fuzzy weights of the sub-criteria with respect to Added Value.

Sub- criteria	Fuzzy Weights(w_i)			BNP_i	$BNPw_i$	Rank
Product Quality	0.258	0.335	0.434	0.342	0.335	2
Production waste	0.272	0.348	0.439	0.353	0.346	1
Profit	0.114	0.146	0.188	0.149	0.146	4
Delivery time	0.133	0.171	0.224	0.176	0.173	3

Table 10. Fuzzy weights of the sub-criteria with respect to Applicability.

Sub- criteria	Fuzzy Weights(w_i)			BNP_i	$BNPw_i$	Rank
Technology	0.087	0.123	0.178	0.129	0.124	4
Skill development	0.150	0.218	0.305	0.224	0.215	1
Growth innovation	0.058	0.082	0.120	0.086	0.083	7
Technique feasibility	0.089	0.128	0.183	0.133	0.128	3
Reliability	0.058	0.082	0.118	0.086	0.082	8
Availability	0.097	0.140	0.202	0.147	0.140	2
Utilization	0.078	0.112	0.161	0.117	0.112	6
Redundancy	0.081	0.116	0.167	0.122	0.116	5

Table 11. Fuzzy weights of the sub-criteria with respect to Equipment Process Control.

Sub- criteria	Fuzzy Weights(w_i)			BNP_i	$BNPw_i$	Rank
Spare part inventories	0.184	0.222	0.263	0.223	0.22	2
Level of service	0.185	0.226	0.280	0.231	0.23	1
Criticality of Machine	0.162	0.201	0.248	0.204	0.20	3
Life Cycle Costing	0.151	0.184	0.224	0.186	0.18	4
Long-term Funding Strategy	0.142	0.167	0.198	0.169	0.17	5

Table 12. Fuzzy weights of the sub-criteria with respect to Safety.

Sub- criteria	Fuzzy Weights(w_i)			BNP_i	$BNPw_i$	Rank
Facilities	0.246	0.340	0.465	0.350	0.339	2
Health and safety training	0.264	0.360	0.486	0.370	0.359	1
Personnel safety	0.100	0.135	0.184	0.139	0.135	4
Environment	0.122	0.165	0.231	0.173	0.167	3

Table 13. Fuzzy weights of the sub-criteria with respect to Cost.

Sub- criteria	Fuzzy Weights(wi)			BNP _i	BNPw _i	Rank
Production cost	0.170	0.209	0.258	0.212	0.209	2
Consultation	0.155	0.193	0.242	0.197	0.194	4
Spare parts cost	0.173	0.220	0.274	0.222	0.219	1
Specialist employee	0.148	0.183	0.230	0.187	0.184	5
Hardware and software	0.158	0.194	0.239	0.197	0.194	3

Table 14. Fuzzy weights of the sub-criteria with respect to Effectiveness.

Sub- criteria	Fuzzy Weights(wi)			BNP _i	BNPw _i	Rank
Efficiency	0.107	0.151	0.218	0.159	0.153	2
Productivity	0.170	0.244	0.339	0.251	0.241	1
Customer satisfaction	0.066	0.092	0.133	0.097	0.093	6
Maintainability	0.102	0.145	0.207	0.152	0.145	4
Reparability	0.065	0.091	0.131	0.095	0.092	7
Conformity	0.105	0.150	0.215	0.157	0.150	3
Functionality	0.089	0.126	0.181	0.132	0.126	5

7) Defuzzification

The average of the fuzzy values for each criterion, which was based on Eq. (15), was used to determine the relative non-fuzzy weight or defuzzified weight of each criterion. The calculation of defuzzification was as follows.

$$BNP_i = \frac{[(Uw_i - Lw_i) + (Mw_i - Lw_i)]}{3} + Lw_i$$

$$BNP_{i=1} = [(0.299 - 0.124) + (0.191 - 0.124)]/3 + 0.124$$

$$BNP_{i=1} = 0.205$$

8) Normalizing the defuzzified weight of criterion.

Then, the defuzzified weights must be normalized using Eq.

(16) along with the normalized weights for each criterion. Therefore, the normalization weight of C₁ can be calculated as follows:

$$BNPw_1 = \frac{BNP_1}{(BNP_1 + BNP_2 + \dots + BNP_n)}$$

$$BNP_{w1} = 0.205 / (0.205 + 0.343 + 0.093 + 0.175 + 0.084 + 0.166) = 0.192$$

Similarly, the BNP value of the remaining dimension and sub-criteria can be obtained in a similar computational procedure (see Table 15). The normalized weights of the sub-criteria placed at the third level in the hierarchy structure can be presented in Table 15.

Table 15. Weighted values and rankings considered by decision experts.

Dimension	Local Weight	Sub criteria (Cij)	Local Weights	Global Weights	Ranking by Category	Overall Ranking
Added Value	0.192	Product Quality	0.335	0.064	2	3
		Production waste	0.346	0.066	1	2
		Profit	0.146	0.028	4	13
		Delivery time	0.173	0.033	3	12

Dimension	Local Weight	Sub criteria (Cij)	Local Weights	Global Weights	Ranking by Category	Overall Ranking
Applicability	0.322	Technology	0.124	0.040	4	8
		Skill development	0.215	0.069	1	1
		Growth innovation	0.083	0.027	7	15
		Technique feasibility	0.128	0.041	3	7
		Reliability	0.082	0.027	8	16
		Availability	0.140	0.045	2	6
		Utilization	0.112	0.036	6	11
Equipment Process Control	0.088	Redundancy	0.116	0.037	5	10
		Spare part inventories	0.220	0.019	2	23
		Level of service	0.228	0.020	1	21
		Criticality of Machine	0.201	0.018	3	24
		Life Cycle Costing	0.184	0.016	4	27
		Long-term Funding Strategy	0.167	0.015	5	30
		Facilities	0.339	0.056	2	5
Safety	0.164	Health and safety training	0.359	0.059	1	4
		Personnel safety	0.135	0.022	4	20
		Environment	0.167	0.027	3	14
Cost	0.079	Production cost	0.209	0.017	2	26
		Consultation	0.194	0.015	4	29
		Spare parts cost	0.219	0.017	1	25
		Specialist employee	0.184	0.015	5	31
		Hardware and software	0.194	0.015	3	28
		Efficiency	0.153	0.024	2	17
		Productivity	0.241	0.038	1	9
Effectiveness	0.156	Customer satisfaction	0.093	0.014	6	32
		Maintainability	0.145	0.023	4	19
		Reparability	0.092	0.014	7	33
		Conformity	0.150	0.023	3	18
		Functionality	0.126	0.020	5	22

4.3. Fuzzy TOPSIS Results

1) Determine the weighting of evaluation criteria.

The fuzzy preference weights for the main criteria and sub-criteria were presented in [Tables 8-14](#).

Table 16. Linguistic terms and their numerical intervals for fuzzy TOPSIS [46].

Linguistic variable	Corresponding triangular fuzzy number
Very Low Important (VLI)	(1, 2, 3)

Linguistic variable	Corresponding triangular fuzzy number
Low Important (LI)	(2, 3, 4)
Moderately Important (MI)	(3, 4, 5)
Highly Important (HI)	(4, 5, 6)
Extremely Important (EI)	(5, 7, 9)

2) Construct the fuzzy-decision matrix and choose the appropriate linguistic variables for the alternatives with respect to the criteria. This paper focuses on determining the best maintenance strategy for the questionnaire that is collected completely and will start with building the dataset that is collected.

3) Normalize the fuzzy decision matrix.

Using Eq. (17), It can normalize the fuzzy decision matrix as it was presented in Table 18.

4) Establish the weighted normalized fuzzy decision matrix.

The fourth step in the analysis is to find the weighted fuzzy decision matrix and the resulting fuzzy weighted

decision matrix is shown in Table 19.

5) Determine the fuzzy positive and fuzzy negative ideal reference points.

Then the fuzzy positive-ideal solution (FPIS) and the fuzzy negative-ideal solution (FNIS) as: A^+ and A^- . This is the fifth step of the fuzzy TOPSIS analysis.

$$A^+ = [(1, 1, 1)]$$

$$A^- = [(0, 0, 0)]$$

6) Ranking the alternatives.

Once the distances of Alternatives from FPIS and FNIS are determined, the closeness coefficient can be obtained by using Eq. (24).

Table 17. Aggregated Fuzzy Decision Matrix for Alternatives by decision experts.

Criteria	Alternatives							
	CM	TBM	PM	TPM	CBM	OM	RM	RCM
C1	3.267, 4.267, 5.133	3.733, 4.867, 5.933	2.933, 4.067, 5.067	3.400, 4.533, 5.533	2.467, 3.533, 4.467	2.200, 3.200, 4.067	2.667, 3.733, 4.533	2.933, 3.933, 4.933
C2	3.933, 5.200, 6.267	4.000, 5.200, 6.267	2.667, 3.733, 4.600	2.933, 4.000, 4.933	2.400, 3.400, 4.133	2.533, 3.533, 4.133	3.733, 4.867, 5.933	3.000, 4.067, 5.000
C3	3.733, 4.867, 5.667	4.067, 5.267, 6.200	3.067, 4.133, 4.667	3.200, 4.400, 5.400	3.933, 5.000, 6.067	2.733, 3.733, 4.267	2.667, 3.667, 4.467	2.533, 3.533, 4.400
C4	3.333, 4.533, 5.533	3.933, 5.200, 6.333	2.800, 3.800, 4.533	2.933, 4.133, 5.067	2.733, 3.800, 4.867	2.200, 3.200, 4.133	2.200, 3.200, 4.000	2.600, 3.600, 4.467
C5	2.600, 3.600, 4.467	3.800, 5.000, 5.800	4.133, 5.400, 6.600	2.933, 3.933, 4.733	3.067, 4.133, 5.200	3.533, 4.800, 6.067	1.867, 2.867, 3.867	1.867, 2.867, 3.867
C6	2.200, 3.200, 4.200	3.600, 4.733, 5.867	4.600, 6.267, 7.933	2.933, 3.933, 4.933	3.200, 4.333, 5.467	2.867, 3.867, 4.867	2.533, 3.600, 4.667	2.333, 3.333, 4.333
C7	2.400, 3.400, 4.400	3.333, 4.467, 5.600	3.800, 4.867, 5.933	2.533, 3.600, 4.667	2.600, 3.600, 4.600	3.467, 4.667, 5.867	2.200, 3.200, 4.200	2.133, 3.133, 4.133
C8	2.600, 3.600, 4.600	3.467, 4.600, 5.733	4.133, 5.333, 6.533	2.533, 3.667, 4.800	2.800, 4.000, 5.200	3.333, 4.600, 5.867	2.200, 3.200, 4.200	2.267, 3.267, 4.267
C9	2.200, 3.200, 4.200	3.133, 4.133, 5.133	3.800, 5.000, 6.200	3.600, 4.733, 5.867	2.733, 3.733, 4.733	2.533, 3.533, 4.533	2.133, 3.133, 4.133	2.133, 3.133, 4.133
C10	2.267, 3.267, 4.267	3.533, 4.667, 5.800	4.000, 5.133, 6.267	3.467, 4.733, 6.000	2.533, 3.667, 4.800	2.533, 3.533, 4.533	2.133, 3.133, 4.133	2.267, 3.267, 4.267

Criteria	Alternatives							
	CM	TBM	PM	TPM	CBM	OM	RM	RCM
C11	2.533, 3.533, 4.533	3.200, 4.200, 5.200	3.667, 4.733, 5.800	2.800, 3.800, 4.800	2.600, 3.733, 4.867	3.133, 4.133, 5.333	2.400, 3.133, 4.133	2.333, 3.133, 4.133
C12	2.867, 3.733, 4.800	3.667, 4.600, 5.733	3.733, 4.733, 5.867	2.933, 4.067, 5.333	3.267, 4.400, 5.667	3.067, 4.067, 5.067	2.533, 3.400, 4.400	2.333, 3.200, 4.200
C13	2.400, 3.400, 4.400	3.333, 4.467, 5.600	3.933, 5.267, 6.600	2.800, 3.867, 4.933	3.333, 4.533, 5.733	2.533, 3.533, 4.533	2.733, 3.733, 4.733	2.800, 3.800, 4.800
C14	2.400, 3.400, 4.400	3.467, 4.467, 5.467	3.800, 4.933, 6.067	3.400, 4.467, 5.533	3.067, 4.133, 5.200	2.600, 3.600, 4.600	2.000, 3.000, 4.000	1.933, 3.000, 4.067
C15	2.267, 3.267, 4.267	3.667, 4.733, 5.800	3.867, 5.067, 6.067	3.333, 4.333, 5.133	2.733, 3.733, 4.733	3.133, 4.267, 5.200	2.600, 3.600, 4.400	2.733, 3.733, 4.533
C16	2.267, 3.267, 4.067	3.467, 4.600, 5.533	3.933, 5.267, 6.400	3.200, 4.333, 5.467	3.267, 4.467, 5.467	3.467, 4.667, 5.667	2.867, 3.667, 4.667	3.000, 3.667, 4.733
C17	2.800, 3.400, 4.400	4.000, 5.000, 6.200	4.333, 5.533, 7.000	3.133, 4.000, 5.133	2.733, 3.467, 4.467	3.067, 4.067, 5.200	2.467, 3.067, 4.067	2.867, 3.467, 4.467
C18	2.867, 3.333, 4.333	3.933, 5.133, 6.600	3.933, 4.867, 6.067	2.933, 3.667, 4.667	3.133, 4.067, 5.267	3.400, 4.333, 5.533	2.867, 3.400, 4.467	3.000, 3.600, 4.600
C19	3.400, 3.533, 4.533	3.800, 4.533, 5.733	4.600, 4.933, 6.267	2.933, 3.733, 4.733	2.933, 3.933, 4.933	4.467, 5.600, 7.133	3.933, 5.067, 6.600	2.000, 2.800, 3.800
C20	2.533, 3.333, 4.333	3.733, 4.667, 5.800	3.267, 4.200, 5.333	2.867, 4.067, 5.267	2.267, 3.067, 4.067	3.400, 4.333, 5.467	3.600, 4.600, 6.000	2.733, 3.533, 4.533
C21	2.467, 3.267, 4.267	3.800, 4.800, 6.000	3.200, 4.133, 5.267	2.533, 3.400, 4.467	2.933, 4.067, 5.200	3.600, 4.533, 5.667	4.000, 5.067, 6.533	2.533, 3.400, 4.467
C22	3.267, 4.067, 5.067	3.467, 4.600, 5.733	4.000, 5.267, 6.533	2.667, 3.667, 4.667	3.400, 4.600, 5.800	3.533, 4.733, 5.933	2.867, 3.867, 4.867	2.267, 3.267, 4.267
C23	2.400, 3.400, 4.400	3.200, 4.267, 5.333	3.800, 4.933, 6.067	2.800, 3.800, 4.800	2.267, 3.267, 4.267	3.267, 4.267, 5.267	2.533, 3.600, 4.667	2.000, 3.000, 4.000
C24	2.333, 3.333, 4.333	2.733, 3.800, 4.867	4.000, 5.133, 6.267	2.467, 3.667, 4.867	3.000, 4.067, 5.133	3.467, 4.533, 5.600	2.600, 3.733, 4.867	2.467, 3.467, 4.467
C25	2.600, 3.600, 4.600	2.867, 3.933, 5.000	3.467, 4.533, 5.600	3.000, 4.067, 5.133	2.733, 3.733, 4.733	3.333, 4.400, 5.467	2.533, 3.533, 4.533	2.200, 3.200, 4.200
C26	2.400, 3.400, 4.400	3.467, 4.733, 6.000	4.000, 5.333, 6.667	3.200, 4.333, 5.467	3.000, 4.067, 5.133	3.533, 4.600, 5.667	2.733, 3.800, 4.867	2.000, 3.000, 4.000
C27	2.533, 3.533, 4.533	3.133, 4.200, 5.267	4.000, 5.267, 6.533	2.733, 3.800, 4.867	3.467, 4.600, 5.733	3.200, 4.200, 5.200	2.600, 3.667, 4.733	2.400, 3.400, 4.400
C28	2.467, 3.467, 4.467	3.200, 4.333, 5.467	3.733, 4.933, 6.133	2.600, 3.667, 4.733	3.400, 4.600, 5.800	3.133, 4.200, 5.267	2.600, 3.600, 4.600	1.933, 2.933, 3.933
C29	2.133, 3.133, 4.133	3.333, 4.467, 5.600	4.000, 5.267, 6.533	3.200, 4.467, 5.733	3.067, 4.133, 5.200	3.733, 4.867, 6.000	2.933, 3.933, 4.933	2.200, 3.200, 4.200
C30	2.333, 3.333, 4.333	3.267, 4.400, 5.533	3.800, 4.933, 6.067	3.400, 4.467, 5.533	2.533, 3.533, 4.533	3.000, 4.133, 5.267	2.600, 3.667, 4.733	1.867, 2.867, 3.867
C31	2.200, 3.200, 4.200	2.600, 3.600, 4.600	3.400, 4.533, 5.667	2.933, 3.933, 4.933	2.600, 3.667, 4.733	2.867, 4.000, 5.133	2.533, 3.533, 4.533	2.467, 3.533, 4.600
C32	2.867, 4.000, 5.133	3.067, 4.067, 5.067	3.667, 4.867, 6.067	2.933, 4.000, 5.067	3.267, 4.333, 5.400	3.067, 4.267, 5.467	2.733, 3.867, 5.000	2.667, 3.733, 4.800

Criteria	Alternatives							
	CM	TBM	PM	TPM	CBM	OM	RM	RCM
C33	3.000, 4.000, 5.000	3.600, 4.667, 5.733	2.933, 4.133, 5.333	2.800, 3.800, 4.800	3.067, 4.200, 5.333	2.867, 3.933, 5.000	2.333, 3.333, 4.333	2.400, 3.400, 4.400

Table 18. Normalized Fuzzy Decision Matrix for Alternatives by Decision experts.

Criteria	Alternatives							
	CM	TBM	PM	TPM	CBM	OM	RM	RCM
C1	0.412, 0.538, 0.647	0.471, 0.613, 0.748	0.370, 0.513, 0.639	0.429, 0.571, 0.697	0.311, 0.445, 0.563	0.277, 0.403, 0.513	0.336, 0.471, 0.571	0.370, 0.496, 0.622
C2	0.496, 0.655, 0.790	0.504, 0.655, 0.790	0.336, 0.471, 0.580	0.370, 0.504, 0.622	0.303, 0.429, 0.521	0.319, 0.445, 0.521	0.471, 0.613, 0.748	0.378, 0.513, 0.630
C3	0.471, 0.613, 0.714	0.513, 0.664, 0.782	0.387, 0.521, 0.588	0.403, 0.555, 0.681	0.496, 0.630, 0.765	0.345, 0.471, 0.538	0.336, 0.462, 0.563	0.319, 0.445, 0.555
C4	0.420, 0.571, 0.697	0.496, 0.655, 0.798	0.353, 0.479, 0.571	0.370, 0.521, 0.639	0.345, 0.479, 0.613	0.277, 0.403, 0.521	0.277, 0.403, 0.504	0.328, 0.454, 0.563
C5	0.328, 0.454, 0.563	0.479, 0.630, 0.731	0.521, 0.681, 0.832	0.370, 0.496, 0.597	0.387, 0.521, 0.655	0.445, 0.605, 0.765	0.235, 0.361, 0.487	0.235, 0.361, 0.487
C6	0.277, 0.403, 0.529	0.454, 0.597, 0.739	0.580, 0.790, 1.000	0.370, 0.496, 0.622	0.403, 0.546, 0.689	0.361, 0.487, 0.613	0.319, 0.454, 0.588	0.294, 0.420, 0.546
C7	0.303, 0.429, 0.555	0.420, 0.563, 0.706	0.479, 0.613, 0.748	0.319, 0.454, 0.588	0.328, 0.454, 0.580	0.437, 0.588, 0.739	0.277, 0.403, 0.529	0.269, 0.395, 0.521
C8	0.328, 0.454, 0.580	0.437, 0.580, 0.723	0.521, 0.672, 0.824	0.319, 0.462, 0.605	0.353, 0.504, 0.655	0.420, 0.580, 0.739	0.277, 0.403, 0.529	0.286, 0.412, 0.538
C9	0.277, 0.403, 0.529	0.395, 0.521, 0.647	0.479, 0.630, 0.782	0.454, 0.597, 0.739	0.345, 0.471, 0.597	0.319, 0.445, 0.571	0.269, 0.395, 0.521	0.269, 0.395, 0.521
C10	0.286, 0.412, 0.538	0.445, 0.588, 0.731	0.504, 0.647, 0.790	0.437, 0.597, 0.756	0.319, 0.462, 0.605	0.319, 0.445, 0.571	0.269, 0.395, 0.521	0.286, 0.412, 0.538
C11	0.319, 0.445, 0.571	0.403, 0.529, 0.655	0.462, 0.597, 0.731	0.353, 0.479, 0.605	0.328, 0.471, 0.613	0.395, 0.521, 0.672	0.303, 0.395, 0.521	0.294, 0.395, 0.521
C12	0.361, 0.471, 0.605	0.462, 0.580, 0.723	0.471, 0.597, 0.739	0.370, 0.513, 0.672	0.412, 0.555, 0.714	0.387, 0.513, 0.639	0.319, 0.429, 0.555	0.294, 0.403, 0.529
C13	0.303, 0.429, 0.555	0.420, 0.563, 0.706	0.496, 0.664, 0.832	0.353, 0.487, 0.622	0.420, 0.571, 0.723	0.319, 0.445, 0.571	0.345, 0.471, 0.597	0.353, 0.479, 0.605

Criteria	Alternatives							
	CM	TBM	PM	TPM	CBM	OM	RM	RCM
C14	0.303, 0.429, 0.555	0.437, 0.563, 0.689	0.479, 0.622, 0.765	0.429, 0.563, 0.697	0.387, 0.521, 0.655	0.328, 0.454, 0.580	0.252, 0.378, 0.504	0.244, 0.378, 0.513
C15	0.286, 0.412, 0.538	0.462, 0.597, 0.731	0.487, 0.639, 0.765	0.420, 0.546, 0.647	0.345, 0.471, 0.597	0.395, 0.538, 0.655	0.328, 0.454, 0.555	0.345, 0.471, 0.571
C16	0.286, 0.412, 0.513	0.437, 0.580, 0.697	0.496, 0.664, 0.807	0.403, 0.546, 0.689	0.412, 0.563, 0.689	0.437, 0.588, 0.714	0.361, 0.462, 0.588	0.378, 0.462, 0.597
C17	0.353, 0.429, 0.555	0.504, 0.630, 0.782	0.546, 0.697, 0.882	0.395, 0.504, 0.647	0.345, 0.437, 0.563	0.387, 0.513, 0.655	0.311, 0.387, 0.513	0.361, 0.437, 0.563
C18	0.361, 0.420, 0.546	0.496, 0.647, 0.832	0.496, 0.613, 0.765	0.370, 0.462, 0.588	0.395, 0.513, 0.664	0.429, 0.546, 0.697	0.361, 0.429, 0.563	0.378, 0.454, 0.580
C19	0.429, 0.445, 0.571	0.479, 0.571, 0.723	0.580, 0.622, 0.790	0.370, 0.471, 0.597	0.370, 0.496, 0.622	0.563, 0.706, 0.899	0.496, 0.639, 0.832	0.252, 0.353, 0.479
C20	0.319, 0.420, 0.546	0.471, 0.588, 0.731	0.412, 0.529, 0.672	0.361, 0.513, 0.664	0.286, 0.387, 0.513	0.429, 0.546, 0.689	0.454, 0.580, 0.756	0.345, 0.445, 0.571
C21	0.311, 0.412, 0.538	0.479, 0.605, 0.756	0.403, 0.521, 0.664	0.319, 0.429, 0.563	0.370, 0.513, 0.655	0.454, 0.571, 0.714	0.504, 0.639, 0.824	0.319, 0.429, 0.563
C22	0.412, 0.513, 0.639	0.437, 0.580, 0.723	0.504, 0.664, 0.824	0.336, 0.462, 0.588	0.429, 0.580, 0.731	0.445, 0.597, 0.748	0.361, 0.487, 0.613	0.286, 0.412, 0.538
C23	0.303, 0.429, 0.555	0.403, 0.538, 0.672	0.479, 0.622, 0.765	0.353, 0.479, 0.605	0.286, 0.412, 0.538	0.412, 0.538, 0.664	0.319, 0.454, 0.588	0.252, 0.378, 0.504
C24	0.294, 0.420, 0.546	0.345, 0.479, 0.613	0.504, 0.647, 0.790	0.311, 0.462, 0.613	0.378, 0.513, 0.647	0.437, 0.571, 0.706	0.328, 0.471, 0.613	0.311, 0.437, 0.563
C25	0.328, 0.454, 0.580	0.361, 0.496, 0.630	0.437, 0.571, 0.706	0.378, 0.513, 0.647	0.345, 0.471, 0.597	0.420, 0.555, 0.689	0.319, 0.445, 0.571	0.277, 0.403, 0.529
C26	0.303, 0.429, 0.555	0.437, 0.597, 0.756	0.504, 0.672, 0.840	0.403, 0.546, 0.689	0.378, 0.513, 0.647	0.445, 0.580, 0.714	0.345, 0.479, 0.613	0.252, 0.378, 0.504
C27	0.319, 0.445, 0.571	0.395, 0.529, 0.664	0.504, 0.664, 0.824	0.345, 0.479, 0.613	0.437, 0.580, 0.723	0.403, 0.529, 0.655	0.328, 0.462, 0.597	0.303, 0.429, 0.555
C28	0.311, 0.437, 0.563	0.403, 0.546, 0.689	0.471, 0.622, 0.773	0.328, 0.462, 0.597	0.429, 0.580, 0.731	0.395, 0.529, 0.664	0.328, 0.454, 0.580	0.244, 0.370, 0.496
C29	0.269, 0.395, 0.521	0.420, 0.563, 0.706	0.504, 0.664, 0.824	0.403, 0.563, 0.723	0.387, 0.521, 0.655	0.471, 0.613, 0.756	0.370, 0.496, 0.622	0.277, 0.403, 0.529

Criteria	Alternatives							
	CM	TBM	PM	TPM	CBM	OM	RM	RCM
C30	0.294, 0.420, 0.546	0.412, 0.555, 0.697	0.479, 0.622, 0.765	0.429, 0.563, 0.697	0.319, 0.445, 0.571	0.378, 0.521, 0.664	0.328, 0.462, 0.597	0.235, 0.361, 0.487
C31	0.277, 0.403, 0.529	0.328, 0.454, 0.580	0.429, 0.571, 0.714	0.370, 0.496, 0.622	0.328, 0.462, 0.597	0.361, 0.504, 0.647	0.319, 0.445, 0.571	0.311, 0.445, 0.580
C32	0.361, 0.504, 0.647	0.387, 0.513, 0.639	0.462, 0.613, 0.765	0.370, 0.504, 0.639	0.412, 0.546, 0.681	0.387, 0.538, 0.689	0.345, 0.487, 0.630	0.336, 0.471, 0.605
C33	0.378, 0.504, 0.630	0.454, 0.588, 0.723	0.370, 0.521, 0.672	0.353, 0.479, 0.605	0.387, 0.529, 0.672	0.361, 0.496, 0.630	0.294, 0.420, 0.546	0.303, 0.429, 0.555

Table 19. Weighted Normalized Fuzzy Decision Matrix by Decision Experts.

Criteria	Alternatives							
	CM	TBM	PM	TPM	CBM	OM	RM	RCM
C1	0.106, 0.180, 0.281	0.122, 0.205, 0.325	0.096, 0.172, 0.277	0.111, 0.191, 0.303	0.080, 0.149, 0.245	0.072, 0.135, 0.223	0.087, 0.157, 0.248	0.096, 0.166, 0.270
C2	0.135, 0.228, 0.346	0.137, 0.228, 0.346	0.092, 0.164, 0.254	0.101, 0.176, 0.273	0.082, 0.149, 0.229	0.087, 0.155, 0.229	0.128, 0.214, 0.328	0.103, 0.179, 0.276
C3	0.054, 0.090, 0.135	0.058, 0.097, 0.147	0.044, 0.076, 0.111	0.046, 0.081, 0.128	0.056, 0.092, 0.144	0.039, 0.069, 0.101	0.038, 0.068, 0.106	0.036, 0.065, 0.105
C4	0.056, 0.098, 0.157	0.066, 0.112, 0.179	0.047, 0.082, 0.128	0.049, 0.089, 0.143	0.046, 0.082, 0.138	0.037, 0.069, 0.117	0.037, 0.069, 0.113	0.044, 0.078, 0.126
C5	0.028, 0.056, 0.100	0.041, 0.077, 0.130	0.045, 0.084, 0.148	0.032, 0.061, 0.106	0.033, 0.064, 0.117	0.039, 0.074, 0.136	0.020, 0.044, 0.087	0.020, 0.044, 0.087
C6	0.041, 0.088, 0.162	0.068, 0.130, 0.226	0.087, 0.172, 0.305	0.055, 0.108, 0.190	0.060, 0.119, 0.210	0.054, 0.106, 0.187	0.048, 0.099, 0.179	0.044, 0.091, 0.167
C7	0.017, 0.035, 0.066	0.024, 0.046, 0.085	0.028, 0.050, 0.090	0.018, 0.037, 0.070	0.019, 0.037, 0.069	0.025, 0.048, 0.089	0.016, 0.033, 0.063	0.016, 0.032, 0.062
C8	0.029, 0.058, 0.106	0.039, 0.074, 0.133	0.046, 0.086, 0.151	0.028, 0.059, 0.111	0.031, 0.065, 0.120	0.037, 0.074, 0.136	0.025, 0.052, 0.097	0.025, 0.053, 0.099
C9	0.016, 0.033, 0.063	0.023, 0.043, 0.076	0.028, 0.052, 0.092	0.026, 0.049, 0.087	0.020, 0.038, 0.071	0.019, 0.036, 0.068	0.016, 0.032, 0.062	0.016, 0.032, 0.062
C10	0.028, 0.058, 0.108	0.043, 0.083, 0.148	0.049, 0.091, 0.160	0.042, 0.084, 0.153	0.031, 0.065, 0.122	0.031, 0.062, 0.116	0.026, 0.055, 0.105	0.028, 0.058, 0.109

Criteria	Alternatives							
	CM	TBM	PM	TPM	CBM	OM	RM	RCM
	0.109							
C11	0.025, 0.050, 0.092	0.031, 0.059, 0.105	0.036, 0.067, 0.117	0.027, 0.053, 0.097	0.025, 0.052, 0.099	0.031, 0.058, 0.108	0.023, 0.044, 0.084	0.023, 0.044, 0.084
C12	0.029, 0.055, 0.101	0.038, 0.067, 0.121	0.038, 0.069, 0.124	0.030, 0.060, 0.112	0.033, 0.064, 0.120	0.031, 0.060, 0.107	0.026, 0.050, 0.093	0.024, 0.047, 0.089
C13	0.056, 0.095, 0.146	0.077, 0.125, 0.186	0.091, 0.147, 0.219	0.065, 0.108, 0.163	0.077, 0.127, 0.190	0.059, 0.099, 0.150	0.063, 0.104, 0.157	0.065, 0.106, 0.159
C14	0.056, 0.097, 0.155	0.081, 0.128, 0.193	0.089, 0.141, 0.214	0.079, 0.128, 0.195	0.072, 0.118, 0.183	0.061, 0.103, 0.162	0.047, 0.086, 0.141	0.045, 0.086, 0.143
C15	0.046, 0.083, 0.133	0.075, 0.120, 0.181	0.079, 0.128, 0.190	0.068, 0.110, 0.160	0.056, 0.094, 0.148	0.064, 0.108, 0.162	0.053, 0.091, 0.137	0.056, 0.094, 0.142
C16	0.043, 0.076, 0.115	0.066, 0.107, 0.157	0.075, 0.122, 0.181	0.061, 0.100, 0.155	0.062, 0.103, 0.155	0.066, 0.108, 0.160	0.055, 0.085, 0.132	0.057, 0.085, 0.134
C17	0.050, 0.072, 0.110	0.072, 0.105, 0.155	0.077, 0.117, 0.175	0.056, 0.084, 0.128	0.049, 0.073, 0.112	0.055, 0.086, 0.130	0.044, 0.065, 0.102	0.051, 0.073, 0.112
C18	0.089, 0.143, 0.254	0.122, 0.220, 0.387	0.122, 0.208, 0.356	0.091, 0.157, 0.274	0.097, 0.174, 0.309	0.105, 0.186, 0.324	0.089, 0.146, 0.262	0.093, 0.154, 0.270
C19	0.113, 0.160, 0.278	0.127, 0.206, 0.352	0.153, 0.224, 0.384	0.098, 0.169, 0.290	0.098, 0.179, 0.302	0.149, 0.254, 0.437	0.131, 0.230, 0.405	0.067, 0.127, 0.233
C20	0.032, 0.057, 0.100	0.047, 0.079, 0.134	0.041, 0.071, 0.123	0.036, 0.069, 0.122	0.029, 0.052, 0.094	0.043, 0.074, 0.127	0.045, 0.078, 0.139	0.034, 0.060, 0.105
C21	0.038, 0.068, 0.124	0.058, 0.100, 0.175	0.049, 0.086, 0.154	0.039, 0.071, 0.130	0.045, 0.085, 0.152	0.055, 0.094, 0.165	0.061, 0.106, 0.190	0.039, 0.071, 0.130
C22	0.070, 0.107, 0.165	0.074, 0.121, 0.187	0.086, 0.139, 0.213	0.057, 0.097, 0.152	0.073, 0.121, 0.189	0.076, 0.125, 0.193	0.061, 0.102, 0.158	0.048, 0.086, 0.139
C23	0.047, 0.083, 0.134	0.063, 0.104, 0.163	0.074, 0.120, 0.185	0.055, 0.093, 0.147	0.044, 0.080, 0.130	0.064, 0.104, 0.161	0.050, 0.088, 0.143	0.039, 0.073, 0.122
C24	0.051, 0.092, 0.150	0.059, 0.105, 0.168	0.087, 0.142, 0.216	0.054, 0.102, 0.168	0.065, 0.113, 0.177	0.075, 0.126, 0.193	0.057, 0.103, 0.168	0.054, 0.096, 0.154
C25	0.048, 0.083, 0.134	0.053, 0.091, 0.145	0.065, 0.105, 0.163	0.056, 0.094, 0.149	0.051, 0.086, 0.137	0.062, 0.102, 0.159	0.047, 0.082, 0.132	0.041, 0.074, 0.122
C26	0.048, 0.083, 0.134	0.069, 0.116, 0.181	0.080, 0.131, 0.201	0.064, 0.106, 0.165	0.060, 0.100, 0.155	0.070, 0.113, 0.171	0.055, 0.093, 0.147	0.040, 0.073, 0.121

Criteria	Alternatives							
	CM	TBM	PM	TPM	CBM	OM	RM	RCM
	0.133							
C27	0.034, 0.067, 0.125	0.042, 0.080, 0.145	0.054, 0.101, 0.180	0.037, 0.073, 0.134	0.047, 0.088, 0.158	0.043, 0.080, 0.143	0.035, 0.070, 0.130	0.032, 0.065, 0.121
C28	0.053, 0.107, 0.191	0.068, 0.134, 0.233	0.080, 0.152, 0.262	0.056, 0.113, 0.202	0.073, 0.142, 0.248	0.067, 0.129, 0.225	0.056, 0.111, 0.196	0.041, 0.090, 0.168
C29	0.018, 0.036, 0.069	0.028, 0.052, 0.094	0.033, 0.061, 0.110	0.026, 0.052, 0.096	0.025, 0.048, 0.087	0.031, 0.056, 0.101	0.024, 0.046, 0.083	0.018, 0.037, 0.070
C30	0.030, 0.061, 0.113	0.042, 0.081, 0.145	0.049, 0.090, 0.159	0.044, 0.082, 0.145	0.032, 0.065, 0.119	0.038, 0.076, 0.138	0.033, 0.067, 0.124	0.024, 0.053, 0.101
C31	0.018, 0.037, 0.069	0.021, 0.041, 0.076	0.028, 0.052, 0.093	0.024, 0.045, 0.081	0.021, 0.042, 0.078	0.023, 0.046, 0.085	0.021, 0.040, 0.075	0.020, 0.040, 0.076
C32	0.038, 0.076, 0.139	0.041, 0.077, 0.137	0.049, 0.092, 0.164	0.039, 0.076, 0.137	0.043, 0.082, 0.146	0.041, 0.081, 0.148	0.036, 0.073, 0.135	0.035, 0.071, 0.130
C33	0.033, 0.064, 0.114	0.040, 0.074, 0.130	0.033, 0.066, 0.121	0.031, 0.060, 0.109	0.034, 0.067, 0.121	0.032, 0.063, 0.114	0.026, 0.053, 0.099	0.027, 0.054, 0.100

In order to calculate the closeness coefficients of each of the alternatives d_i^- and d_i^+ calculation is used as an example as follows: The closeness coefficient of the first alternative is calculated as:

$$CC_{CM} = \frac{d_i^-}{d_i^- + d_i^+}, d_i^- = 0.628, d_i^+ = 5.233$$

$$CC_{CM} = \frac{d_i^-}{d_i^- + d_i^+}, CC_{RM} = \frac{0.628}{0.628 + 5.233} = 0.107$$

Table 20. Closeness Coefficients and Ranking.

Maintenance Strategies	Closeness Coefficients and Ranking			
	d_i^+	d_i^-	Cci	Rank
Corrective Maintenance (CM)	5.233	0.628	0.107	7
Time-Based Maintenance (TBM)	5.109	0.772	0.131	2
Preventive Maintenance (PM)	5.076	0.796	0.136	1
Total Predictive Maintenance (TPM)	5.186	0.664	0.114	4
Condition Based Maintenance (CBM)	5.190	0.663	0.113	5
Opportunistic Maintenance (OM)	5.166	0.703	0.120	3
Routine Maintenance (RM)	5.222	0.656	0.112	6
Reliability Centered Maintenance (RCM)	5.270	0.577	0.099	8

As a result of the above Fuzzy TOPSIS steps, the Closeness coefficients CC_i of the eight alternatives come out to be 0.107, 0.131, 0.136, 0.114, 0.113, 0.120, 0.112, and 0.099 respectively. Hence the ranking order for preventive maintenance is higher than others, that is, preventive maintenance is the best choice considering the given criteria. The closeness coefficient scores for alternatives are numeric values and can be further utilized to indicate the degree of inferiority or superiority of the alternatives with respect to each other. On the contrary, the ranking order for corrective, and reliability-centered maintenance is lower than others, this indicates that the identified maintenance management strategy cannot achieve the business objectives and the company's strategic goals based on the identified selection criteria.

5. Discussions, Managerial Implications, and Limitations

5.1. Discussion of Results

In this study, a set of thirty-three equipment maintenance strategy selection criteria were considered. This study explored the appropriate set of selection criteria and maintenance strategies for fuzzy AHP and Fuzzy TOPSIS. The combined methodology of fuzzy AHP and fuzzy TOPSIS helps to determine the appropriate selection criteria and maintenance strategy as it was presented in Figure 2. The decision experts weighted the value of the main criteria and sub-criteria as it was presented in Table 15.

As it was observed in Table 15 the decision experts compared local weights in each main criterion and ranked applicability (0.322) and added value (0.192) as the first and second most important maintenance strategy selection criteria. Thus, decision experts believe that applicability, and add value should be viewed as the most important in equipment maintenance management strategy selection criteria. This indicates that the decision experts focus on the applicability of machinery and their business objectives for executing maintenance by considering these criteria. Safety (0.164) is the next most important selection criterion identified by the decision experts followed by effectiveness (0.156). Contrariwise, equipment process control (0.088), and cost (0.079) were the least important selection criterion. This result indicates that the perceptions of the decision experts are influenced by the priority weights of applicability, and add value overshadow this criterion in maintenance strategy selection.

Individually, further examining each sub-criterion under the main criteria the highest and most important selection criteria among the sub-criteria for the applicability category was skill development (0.069), availability (0.045), and technique feasibility (0.041) followed by technology (0.040),

and redundancy (0.037). On the contrary, utilization (0.036), growth innovation (0.027), and reliability (0.027) are the least important criteria.

The greatest weighted value under add value criteria was production waste (0.066) followed by Product quality (0.064), and Delivery time (0.033). On the contrary, profit (0.028) is the least important consideration in the maintenance strategy consideration. The greatest weighted value under safety criteria was the health and safety training (0.059), the facilities (0.056), and the environment (0.027) were identified as the most important selection criteria by the experts. Contrariwise, personnel safety (0.022) is identified as the least important selection criterion. Moreover, the greatest importance sub-criteria under the effectiveness category were productivity (0.038), efficiency (0.024), conformity (0.023), maintainability (0.023), and functionality (0.020). On the contrary, customer satisfaction (0.014), and reparability (0.014) are identified as the least important criteria.

Furthermore, the greatest importance sub-criteria under the equipment process control category were level of service (0.020), spare part inventories (0.019), and criticality of the machine (0.018). On the contrary, Life Cycle Costing (0.016), and Long-term Funding Strategy (0.015) are identified as the least important criteria. Finally, the greatest importance sub-criteria under the cost category were spare parts cost (0.017), production cost (0.017), and hardware and software (0.015). Contrariwise, consultation (0.015), and specialist employee (0.015) are identified as the least important criteria.

Overall, the sub-criteria with the five highest-ranked final weights among global weights were skill development (0.069), production waste (0.066), product quality (0.064), health and safety training (0.059), and facilities (0.056). In this study, eight equipment maintenance management strategies were considered. This study explored the appropriate equipment maintenance strategy for the fuzzy TOPSIS model.

Table 19 shows the closeness coefficient and ranking order of equipment maintenance management strategies considered by decision experts. As was observed in Table 19 the most appropriate equipment maintenance management strategy ranked first as perceived by the experts was preventive maintenance with a closeness coefficient value higher than other alternatives. Hence, the results show that the higher value of the closeness coefficient was obtained for preventive maintenance which is closer to the ideal values for fuzzy TOPSIS.

Contrariwise, the lower value of the closeness coefficient was obtained for corrective maintenance and reliability-centered maintenance. Corrective maintenance management strategies were ranked as the 7th equipment maintenance management strategy by experts. Reliability-centered maintenance was ranked as the 8th equipment maintenance management strategy. This indicates that the closeness coefficients of corrective maintenance, and reliability-centered maintenance management strategies were

far from the ideal value. Therefore, Preventive maintenance was selected as the best equipment maintenance strategy among the considered ones which have the best closeness coefficient value by decision experts.

5.2. Managerial Implications

The outcomes of this research provide some significant implications for maintenance managers and the company in general. The maintenance managers ought to be conscious of the various magnitudes of maintenance in the equipment maintenance strategies, and the implications that they have towards the attainment of maintenance goals. They ought to appreciate that scientific and appropriate strategy selection tools for maintenance can significantly enhance the quality of their maintenance decisions and reduce the errors made in over-or-under-estimating decision variables.

The research a gain provides many important practical implications for making maintenance policies and strategies for the maintenance company. The outcomes of this research prove that although it is necessary to engage in preventive maintenance strategy was identified as the best for the upkeep of the equipment by considering skill development, production waste, product quality, health and safety training, and facilities.

5.3. Limitations

In the course of conducting this research, some knowledge was gained, which reveals the limitations of the techniques or methodologies in this research article. With this insight, it is worthwhile to outline additional methods that could be pursued in the future to extend the frontier of knowledge concerning road maintenance strategy. Here there are some limitations with existing techniques or methods that affect equipment maintenance management strategy evaluation and selection.

The first deficiency of the published paper is during the criteria selection process, in most cases, a large number of sub-criteria were considered for selection purposes, which requires high computational requirements. This also makes the developed fuzzy model more complex and time-consuming as far as the formulation of the historical database is concerned. Few studies would be conducted on the applied methodologies of fuzzy-based approaches, in the literature, though the use of fuzzy set theory is the hot research topic. Thus the method can be used other than the knowledge area.

The other limitation of the proposed methodology was it uses a limited number of decision experts for carrying out the study. Thus, the generalizability of this might be limited. Finally, in this research article, the fuzzy concept has been applied. However, several other fuzzy theories may be applied to make a comparison of the results and to check the consistency of results.

6. Conclusions and Remarks

This research aims to construct a fuzzy AHP and fuzzy TOPSIS model for the evaluation and selection of appropriate equipment maintenance management strategies. The importance of the criteria for the selection of the appropriate maintenance management strategy is evaluated by the decision experts, and the uncertainty of human decision-making is taken into account through the fuzzy concept in a fuzzy environment. From the proposed method, fuzzy AHP helps to find out that applicability and added value can be identified as the most important equipment maintenance strategy selection criteria. The first five important equipment maintenance strategy selection criteria are skill development (0.069), production waste (0.066), product quality (0.064), health and safety training (0.059), and facilities (0.056).

On the other hand, long-term funding strategy (0.015), specialist employee (0.015), customer satisfaction (0.014), and reparability (0.014) can be identified as the least important selection criteria and last priorities among these selection criteria. Moreover, fuzzy TOPSIS methodology helps to determine the best maintenance alternatives.

The finding of the study revealed that the preventive maintenance strategy is identified as the best and the most appropriate equipment maintenance management strategy. This might be the fact that it applies to the conditions and environment even in other countries. This is because it considers complex sustainability statistical equipment assessment that is considered in other countries or regions. Contrariwise, corrective and reliability-centered maintenance management strategies were identified as the least important equipment maintenance management strategies in the company. Moreover, this approach provides a more accurate, systematic, and rational decision-support tool. Further study can apply the other prioritization techniques for finding the weight of criteria and maintenance strategy under a fuzzy environment and the results can be compared with the present method.

Finally, the findings of this study provide academicians and practitioners with insightful information on the introduction of integrated techniques in the construction industry to demonstrate its practicality would be the best area of investigation.

Abbreviations

AHP	Analytical Hierarchy Process
BNP	Best Non-Fuzzy Value
CBM	Condition-Based Maintenance
CI	Consistency Index
CC	Closeness Coefficient
CR	Consistency Ratio
CM	Corrective Maintenance
DOM	Design-Out Maintenance

FNIS	Fuzzy Negative Ideal Solution
FPIS	Fuzzy Positive Ideal Solution
MCDMM	Multi Criteria Decision Making Methods
OM	Opportunistic Maintenance
PM	Preventive Maintenance
RCM	Reliability Centered Maintenance
RI	Random Index
RM	Routine Maintenance
TBM	Time-Based Maintenance
TFN	Triangular Fuzzy Number
TOPSIS	Technique for Order Performance by Similarity to Ideal Solution
TPM	Total Productive Maintenance

Author Contributions

Girmay Getawa Ayalew: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Genet Melkamu Ayalew: Conceptualization, Data curation, Formal Analysis, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Data Availability

The source of data used to support the findings of this study is available from the corresponding author upon request.

Conflict of Interests

The authors declare no conflicts of interest.

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