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Maintenance strategy selection using Fuzzy analytical hierarchy process in gas power plants
A case study in South Baghdad Gas Station*

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Abstract:
This research presents a systematic approach for selecting a maintenance strategy in an industrial facility through the integration of the Analytical Hierarchy Process (AHP) and Fuzzy Logic. The first Baghdad South Gas Power Plant needs to reduce production shutdowns and maintain the safety of the plant and its employees, especially given the significant need to increase maintenance operations. This study aims to select the most appropriate maintenance strategies for the power plant that maintains the plant's efficient operation. The Fuzzy Analytical Hierarchy Process (FAHP) technique was used to determine the relative importance of each of the main and sub-criteria. Microsoft Excel was used to calculate the results. Relative weights were determined based on a pairwise comparison list conducted by three experts in the power plant. The study concluded that time-based maintenance is the most preferred maintenance strategy for decision makers in the power plant. Condition-based maintenance was the second most important strategy. We recommend adopting time-based maintenance and increasing reliance on condition-based and predictive maintenance, while reducing reliance on corrective maintenance.

*The research is extracted from a master's thesis of the first researcher.

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اختيار استراتيجية الصيانة باستخدام عملية التحليل الهرمي الضبابي في محطة الكهرباء الغازية

دراسة حالة في محطة كهرباء جنوب بغداد الغازية*

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المستخلص

يقدم البحث طريقة منهجية لاختيار استراتيجية الصيانة في المنشأة الصناعية عن طريق تكامل عملية التحليل الهرمي والمنطق الضبابي. في ظل حاجة محطة كهرباء جنوب بغداد الغازية الأولى الى تقليل توقفات الإنتاج، والمحافظة على امان المحطة والموظفين. خصوصا مع وجود حاجة كبيرة لزيادة عمليات الصيانة. تسعى هذه الدراسة الى اختيار أكثر استراتيجيات الصيانة ملائمة لمحطة الكهرباء. التي تحافظ على استمرار عمل المحطة بكفاءة. وقد تم استخدام تقنية عملية التحليل الهرمي الضبابي (FAHP). لتحديد الأهمية النسبية لكل من المعايير الرئيسية والفرعية. تم استخدام برنامج (Microsoft Excel) لإيجاد النتائج. وتم تحديد الاوزان النسبية بناء على قائمة المقارنة الثنائية التي أجراها ثلاثة خبراء في المحطة الكهربائية، وخلصت الدراسة الى ان الصيانة المبنية على الوقت هي الصيانة الأكثر تفضيلا بالنسبة لمتخذي القرار في المحطة الكهربائية. وأن الصيانة المبنية على الحالة ثاني أهم استراتيجية. لذا نوصي باعتماد الصيانة المبنية على الوقت. وزيادة الاعتماد على الصيانة المبنية على الحالة والتنبؤية. مقابل تقليل الاعتماد على الصيانة العلاجية.

الكلمات المفتاحية: اتخاذ القرار متعدد المعايير، إدارة الصيانة، سياسة الصيانة، المنطق الضبابي، عملية التحليل الهرمي.

1-Introduction:

Maintenance is one of the areas that plays a vital role in determining productivity. The main objective of a maintenance strategy is to minimize breakdowns and keep the plant in good working condition. The maintenance strategy plays a key role in ensuring long-term system availability. This study is based on the importance of developing a scientific, systematic approach, such as the Analytical Hierarchy Process (AHP), in selecting a maintenance strategy. This approach balances conflicting criteria and desires, in addition to using fuzzy logic to address inaccuracy in expert opinions. The research aims to select a maintenance strategy that ensures the least possible downtime and contributes to increasing the efficiency of maintenance operations. The winning maintenance strategy, the reasons that influenced the evaluation of strategies, and ways to improve the maintenance policy applied in the power plant will be presented. This study aims to provide an integrated methodology that contributes to making

* البحث مستل من رسالة ماجستير للباحث الأول.

strategic decisions that meet the requirements of decision makers, thus contributing to achieving the goals of industrial companies.

Research issue:

The first South Baghdad Gas Power Plant is facing an increasing number of breakdowns and an increased need for maintenance due to the use of heavy liquid fuel, which suffers from impurities. and because of the obsolescence of the power plant components. This impacts production, safety, and the availability of spare parts, some of which are imported and require replacement with the help of companies from different countries, this impacts the efficiency of the power plant.

Research objective:

The research aims to select an appropriate maintenance strategy for the South Baghdad Gas Power Plant, which increases the efficiency of maintenance operations, contributes to reducing maintenance downtime, and increases the safety level for employees and the plant. This is done by ranking the alternatives based on the relative weight of each alternative, using the Fuzzy Analytical Hierarchy Process (FAHP). This requires calculating the Global weights of the criteria and then finding the total weight of the alternatives.

The importance of research:

The research carries scientific and practical importance, as it presents an integrated methodology for selecting a maintenance strategy, using the Fuzzy Analytical Hierarchy Process (FAHP). It also contributes to reducing power plant downtime, increasing safety levels, and improving the management of spare parts stock, thus increasing the overall efficiency of the plant.

Literature Review:

There are numerous studies on maintenance strategy selection. Bevilacqua & Braglia (2000) conducted a study on maintenance strategy selection. The study aimed to identify and group machines into three homogeneous groups and implement the Analytical Hierarchy Process (FAHP) method to select a maintenance strategy. Using a case study in the Italian petroleum industry, the study concluded that the AHP method can address the decision-making problem more completely and comprehensively, taking into account multiple factors compared to a method such as FMECA. Because the method can integrate qualitative and quantitative information, managers can express all factors through pairwise comparison. There is satisfaction with maintenance management derived from the use of the AHP methodology.

Sharma et al (2005) published a study on fuzzy logic-based maintenance strategy selection. The study aimed to develop a fuzzy logic-based model using a multiple-input, single-output (MISO) framework to select the appropriate maintenance strategy for equipment. The study focused on the manufacturing sector. The most important findings of the study were that the proposed model was able to handle uncertainty and provide a more accurate assessment, thus selecting the most beneficial and efficient maintenance strategy. Proactive (CBM) and aggressive (TPM) maintenance strategies were significantly better than traditional reactive maintenance (BDM).

Wang et al (2007) aimed to evaluate different maintenance strategies (e.g., corrective, preventive, time-based, condition-based, and predictive maintenance) for various equipment. They developed a decision-making system based on AHP and Fuzzy Logic to handle uncertainty in expert judgment. The target sector of the research was the power generation industry. The FAHP model is suitable for handling uncertainty and precision in expert judgment. Maintenance strategies were ranked based on their ability to meet organizational objectives. Predictive maintenance is the most suitable strategy for boilers.

Fazlollahtabar & Yousefpoor (2008) conducted a study using the AHP method to evaluate different maintenance strategies (e.g., remedial maintenance, time-based preventive maintenance, condition-based maintenance, and predictive maintenance) for various equipment used in a virtual learning environment. Their most important finding was that the AHP method accurately evaluated criteria, sub criteria, and alternatives. The result of the AHP method is an overall ranking of alternatives. An optimal maintenance strategy combination can improve the availability and reliability levels of plant equipment.

Pun et al. (2017) proposed a decision support system based on the fuzzy analytic hierarchy process (FAHP) for multi-criteria decision making to select the most effective strategy in building maintenance. It was found that by finding the most appropriate strategy, work efficiency can be improved and costs reduced.

Mostafa & Fahmy (2020) studied six different pieces of equipment to evaluate five different maintenance strategies based on multiple criteria, such as cost, wear, and feasibility. They used the Analytical Hierarchy Process (AHP) to solve the maintenance strategy selection problem at a natural gas processing plant. The results showed that the plant needed to make changes to its strategy, which would lead to improved plant resource utilization, reduced total maintenance costs, and increased equipment availability.

Rahman et al. (2021) used the Analytical Hierarchy Process (AHP) technique to make a decision about outsourcing application maintenance. Fifteen influencing factors were used. These factors were then evaluated through a pilot study, which identified 10 critical success factors. The AHP model was then evaluated through three case studies in three companies.

2-Methodology:

Selecting a maintenance strategy for a power plant using the Fuzzy Analytical Hierarchy Process (FAHP) to extract the relative importance of key criteria (safety, business interruption loss, and technical feasibility). These criteria include sub-criteria: personal safety, facility safety, environmental safety, spare parts stock, production loss, quality, reliability, and applicability.

Section One: Theoretical Framework

1-Maintenance:

Maintenance is described as a set of all technical and managerial procedures, including supervisory procedures, that aim to maintain or restore an item to a condition in which it can perform the required function (Lagnebäck, 2007: p19). Maintenance is defined as a set of all corresponding technical and administrative procedures intended to be maintaining an item or returning it to a condition in which it can perform its required function (BESNARD, 2009: p23).

Most authors of articles and books on maintenance management define it as "the collection of actions needed to maintain or restore equipment, facilities, and other physical assets in a desired operating condition." (Rastegari, 2012: p10).

1.1-Maintenance strategy:

Having a strategy means emphasizing long-term goals rather than short-term ones, establishing wide-ranging, general goals for the organization, detaching yourself from day-to-day work, and concentrating on long-term goals (Kange & Lundell, 2015: p10).

Maintenance strategies are needed because plant and building performance affects quality, costs, and customer needs, and therefore has direct input into the overall profitability (Salonen, 2009: p29). The domain of maintenance is frequently categorized into more specific approaches to how practical maintenance activities are performed (Lagnebäck, 2007: p20). The asset maintenance strategy relies on a coordinated set of core goals and policies for the maintenance process (Salonen, 2009: p30). The strategy is the comprehensive guide for making decisions related to maintenance operations (Kange & Lundell, 2015: p10).

The strategy must aim to achieve the organization's goals; if not, the strategy must be adjusted (Olsen, 2017: p9). In line with manufacturing, corporate, and business-level strategies; in a manner that clarifies and discloses the organizational purpose; and identifies the nature of the economic and non-economic contributions it aims to provide the organization as a whole (Salonen, 2009: p30). The choice of maintenance strategy is significantly affected by the company's business strategy, the characteristics of

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production, the type of production machinery used in the organization and other factors (Žilka, 2014: p210).

1.2- Some of the most important maintenance strategies are:

1.2.1- Corrective Maintenance:

In corrective maintenance or run-to-failure (RTF) strategy, corrective action is implemented to restore a device to a functional state after it has unexpectedly stopped working. This action entails either repairing or replacing the failed component and can be performed as needed (Abbas & Shafiee, 2020: p3). This means that no maintenance procedures are performed until the fault occurs (Žilka, 2014: p210). It is the most basic form of classic maintenance policy where an asset is used until it breaks/fails with the only activity focused on repairing and maintaining the parts. Corrective maintenance can then be Categorized into subtypes according to whether it is done immediately or postponed to a later date (Muyingo, 2009: p6).

1.2.2-time-based preventive maintenance:

Time-based maintenance is preventive maintenance in which tasks are performed regularly depending on the elapsed time regardless of the actual condition of the item (Muyingo, 2009: p6). Preventive maintenance is the process of performing particular inspections, tests, measurements, adjustments, or replacement of parts, specifically intended to prevent breakdowns (Erkoyuncu et al, 2017: p3). Preventive tasks mean substituting components or repairing items at specified intervals, i.e. preventing premature equipment damage and preventing unscheduled downtime (Fredriksson & Larsson, 2012: p30).

1.2.3- Condition-Based Maintenance

The concept of condition-based maintenance is to evaluate the state of technical systems and/or components by monitoring their condition, and to perform maintenance only when potential failures can be predicted. Condition monitoring uses techniques such as vibration analysis and oil analysis (Salonen, 2009: p18). This maintenance strategy respects the actual technical condition assessed through technical diagnostic methods (Žilka, 2014: p210). The test results must be processed to detect, isolate and identify the fault (Achermann, 2008: p17). Machinery and equipment are only shut down when they reach the wear threshold, or the limit values of monitored properties, indicating a risk of failure (Žilka, 2014: p210).

1.2.4- Predictive maintenance

Within a predictive maintenance policy, data is analyzed to detect patterns that can predict performance degradation. Maintenance activities are then scheduled based on future failure times and other relevant factors (Muyingo, 2009: p7). Rotating machines often show signs of imminent failure prior to the ultimate breakdown if appropriate action is not taken in a timely manner.

For example, there may be elevated temperature or cracks in hot parts, increased vibration levels, or changes in vibration patterns and temporal waveforms. There may also be a decrease in performance (Chukwuekwe, 2016: p9). Predictive maintenance relies on the belief that failures can be detected, and action taken prior to their occurrence. Therefore, predictive maintenance is proactive, meaning tasks are performed before failure occurs, thereby preventing failure. Predictive maintenance investigates the conditions that could cause deterioration and lead to failure (Fredriksson & Larsson, 2012: p31).

2-Analytical hierarchy process (AHP)

The Analytical Hierarchy Process (AHP) is a technique invented by Thomas L. Saati in 1981. In AHP, alternatives are assessed based on quantitative and qualitative criteria. This is done in a multi-tiered hierarchical structure. Weight is then assigned to each alternative to determine the overall ranking of the alternatives (Samanlioglu et al, 2018: p3). The AHP method was developed by Al-Saati as a multi-criteria decision-making (MCDM) tool. It models the decision problem in a hierarchical structure consisting of several levels (Wang et al, 2007: p155).

MCDM refers to finding the optimal decision from all available alternatives in the presence of multiple, usually conflicting, evaluation criteria (Torfi, 2010: p520). Multiple criteria decision making (MCDM) methods are frequently used to address real-world problems with multiple, conflicting, and incompatible criteria and/or objectives (Kubler et al, 2016: p2).

In the Analytic Hierarchy process (AHP), decision makers are required to compare each group at the same hierarchical level in a pairwise manner relying on their own experience and knowledge. For example, each time there are two criteria compared with each other’s relative to the objective. Since comparisons are made based on personal or subjective assessments, a certain degree of inconsistency may occur. To ensure consistency of judgments, a final process called consistency checking, one of the biggest advantages of AHP, it performs to measure the degree of consistency between pairwise comparisons by calculating the consistency ratio (Ho, 2008: p212).

To establish priorities, a five-step process is commonly used in the Analytical Hierarchy Process (AHP) (Cheng & Li, 2003: p233):

1- Define the problem to be solved
2- Break down the problem into a hierarchy
3- Apply the pairwise comparison method
4- Calculate the consistency level to eliminate inconsistent answers
5- Assess the relative weights of the components of each level

2.1-Advantages of the Analytical Hierarchy Process (AHP) technique:

1- The extensive use of the AHP methodology across diverse industries has proven its value and increasing validity as a tool in multi-criteria decision analysis (Choi, 2021: p8).

2- The technique of Analytical Hierarchy Process is characterized by the fact that it enables the creation of a hierarchical structure for a multi-criteria decision problem and its grouping into various levels (Wittstruck & Teuteberg, 2012: p210).

Al-Saati (1980) indicates that the popularity of the Analytical Hierarchy Process (AHP) technique stems from three main advantages (Cheng & Li, 2003: p232):

3-It assists in analyzing a realistic, complex, unstructured, multi-criteria decision-making problem (or research problem) into a set of elements represented by variables organized in a multi-level hierarchical form, which also determines general priorities by measuring the personal judgments of the experts.

4-This method employs pairwise comparison process, which entails comparing two elements simultaneously to form a judgment about their relative weights. Because this method compares one element to other elements comprehensively, it provides more useful information for verifying the validity of the results.

5- This technique evaluates the consistency level of each comparison matrix. Some scholars call this consistency measure a consistency test. Especially with appropriate measurements, AHP is more accurate (with reduced experimental errors) in achieving a higher degree of consistency.

2.2-Fuzzy analytical hierarchy process (FAHP)

In AHP, experts' comparisons of main criteria, sub-criteria, and alternatives are expressed in the form of exact numbers. However, in many practical situations, experts' preferences are uncertain, and they are reluctant or unable to make numerical comparisons. Fuzzy decision making is an effective approach for decision-making in an ambiguous environment. Classical decision-making methods only work with precise, regular data, so there is no place for ambiguous data (Torfi, 2010: p520). To address uncertainty and ambiguity in the decision-making process, we use an extension of the Analytical Hierarchy Process (AHP) method, which is complemented by Fuzzy Logic (FHP), which has been developed and effectively used in many Multi-Criteria Decision-Making (MCDM) problems (Samanlioglu et al, 2018: p3).

Zadeh (1965) proposed fuzzy set theory to solve problems in which the interpretation of activities, assessments, and observations is subjective, uncertain, and ambiguous. A fuzzy set can be defined as a collection of objects whose members have varying degrees of group membership. Fuzzy set theory was introduced by Chang (1996) (Valipour et al, 2018: p5-6). Fuzzy set theory is a mathematical theory of non-exact sets. Any crisp set can be fuzzified by extending the concept of a set within this theory to the concept of a fuzzy set (Samanlioglu et al, 2018: p3).

2.3- Fuzzy set arithmetic operations:

Fundamental mathematical operations involving two fuzzy trigonometric numbers $A = (l_1, m_1, u_1)$ and $B = (l_2, m_2, u_2)$ where $l_1 \leq m_1 \leq u_1 . l_2 \leq m_2 \leq u_2$ are presented below (Samanlioglu et al, 2018: p3):

$$\tilde{A} + \tilde{B} = (l_1 + l_2, \quad m_1 + m_2, \quad u_1 + u_2)$$

$$\tilde{A} - \tilde{B} = (l_1 - u_2, \quad m_1 - m_2, \quad u_1 - l_2)$$

$$\tilde{A} \times \tilde{B} = (l_1 \times l_2, \quad m_1 \times m_2, \quad u_1 \times u_2)$$

$$\frac{\tilde{A}}{\tilde{B}} = \left(\frac{l_1}{u_2}, \quad \frac{m_1}{m_2}, \quad \frac{u_1}{l_2}\right)$$

$$\tilde{A}^{-1} = \left(\frac{1}{u_1}, \quad \frac{1}{m_1}, \quad \frac{1}{l_1}\right)$$

Section Two-applied side and the Study results:

1-An overview of the South Baghdad Gas Power Plant:

The first Baghdad South Gas Power Plant was inaugurated in 2005. It consists of two units for generating electricity. A gas power plant generally consists of fuel processing and storage tanks, air filters and compressors, a combustion chamber, a turbine, and a generator. The plant consists of the following departments, which either carry out maintenance work themselves, play a supporting role, or supervise the completion of maintenance work. These departments are as follows: Electrical Department, Mechanical Department, Control Department, Technical Support Department, Processing Department, and Safety and Fire Department. The importance of applying this research to the Baghdad South Gas Power Plant stems from the great need for electricity that Iraq suffers from. In addition, power plants operate continuously, which highlights the importance of maintenance in maintaining the plant under suitable operating conditions and minimizing downtime to the greatest extent possible. Furthermore, the power plant consists of thousands of parts and therefore requires a maintenance strategy that maintains the plant's operating efficiency (prepared by the researcher).

2-Determine the problem hierarchy:

The first step in the AHP process is to create a hierarchical diagram of the problem, in which decisions are made using criteria against which alternatives will be evaluated. Alternatives are the options between which choices are made. The hierarchical model consists of three levels: the problem objective or research goal at the top level; the second, or

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intermediate, level contains the criteria against which evaluation will be conducted; and the lowest level contains the alternatives being evaluated. The problem hierarchy will be as follows:

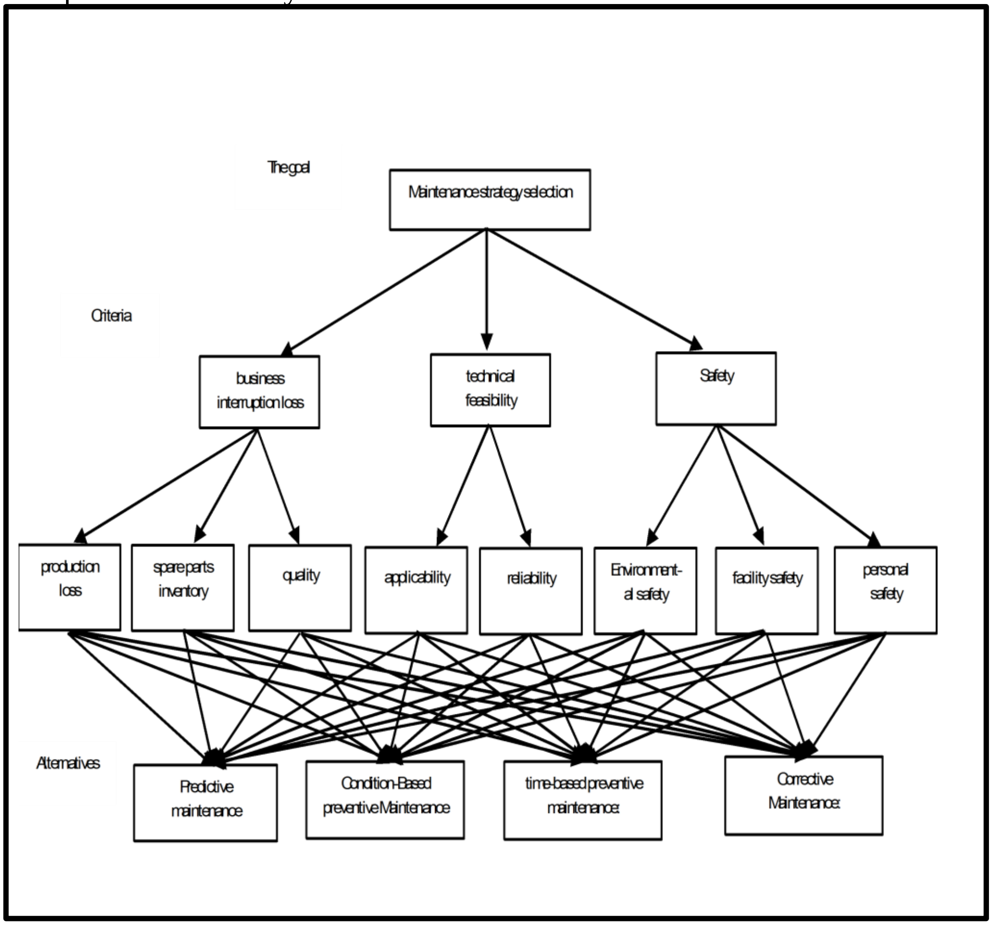

Figure (1): The hierarchical diagram of the problem. Source: Prepared by the researcher

3-Distribution of the pairwise comparison matrix:

After constructing the hierarchical diagram for the research problem, the AHP methodology required a pairwise comparison of the criteria to determine their relative weights. Experts from the power plant were tasked with completing the pairwise comparison matrix. The experts were selected from the maintenance departments. The expert opinions obtained were as follows: the head of the electrical department, an engineer from the mechanical department, and an engineer from the technical support department. The nine-point watchmaker scale was used in the pairwise comparison matrix, as shown in the following table:

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Table (1): An example of the comparison matrix that was used (prepared by the researcher based on the sources)

9	8	7	6	5	4	3	2	criteria	1	criteria	2	3	4	5	6	7	8	9
								business interruption loss		safety								
								technical feasibility		safety								
								technical feasibility		business interruption loss								

4- Data Fuzzing and Aggregate Matrix Calculation:

We then transform the experts' opinions into fuzzy sets to determine judgments using a membership function. A triangular fuzzy set was used to transform linguistic variables into quantitative values in this study, where the pairwise comparison matrix is fuzzy using a triangular fuzzy number M = (l, m, u), where l and u represent the lower and upper bounds of the decision-maker's expressed preferences, respectively. As shown in the following table:

Table (2): Fuzzy triple numbers

Linguistic variables	Fuzzy Triple Numbers	Reciprocal of fuzzy triple numbers
complete preference	(9, 9, 9)	$(\frac{1}{9},\frac{1}{9},\frac{1}{9})$
very strong	(8, 7, 6)	$(\frac{1}{6},\frac{1}{7},\frac{1}{8})$
Strong importance	(6, 5, 4)	$(\frac{1}{4},\frac{1}{5},\frac{1}{6})$
Medium importance	(4, 3, 2)	$(\frac{1}{2},\frac{1}{3},\frac{1}{4})$
equal importance	(1, 1, 1)	$(\frac{1}{1},\frac{1}{1},\frac{1}{1})$
Intermediate values	(9, 8, 7), (7, 6, 5), (5, 4, 3), (3, 2, 1)	$\left(\frac{1}{5},\frac{1}{6},\frac{1}{7}\right),\left(\frac{1}{7},\frac{1}{8},\frac{1}{9}\right),$ $\left(\frac{1}{1},\frac{1}{2},\frac{1}{3}\right),\left(\frac{1}{3},\frac{1}{4},\frac{1}{5}\right)$

Source: Moslem, S., Ghorbanzadeh, O., Blaschke, T., & Duleba, S. (2019). "Analysing stakeholder consensus for a sustainable transport development decision by the fuzzy AHP and interval AHP". Sustainability, 11(12), 3271.

Next, we combine the experts' opinions: To combine the experts' opinions, we use the geometric mean method. As in the following equation, where K represents the number of experts, we use the following formula:

$$, a = (a_1 * a_2 * \dots * a_k)^{1/k} , b = (b_1 * b_2 * \dots * b_k)^{1/k}$$

$$, c = (c_1 * c_2 * \dots * c_k)^{1/k}$$

5-consistency ratio Calculation:

To calculate the consistency ratio (CR) for either standards or alternatives, we follow the following steps:

1-Convert the triple fuzzy numbers (lmi, mwi, umi) in the combined comparison matrix to normal numbers by calculating the average by adding the fuzzy numbers and dividing them on their count.
2-Calculating the normalized matrix C_{norm}: It is calculated by calculating the sum of each column, then dividing each paragraph in the column by the sum of the column.
3-Calculate the arithmetic mean for each row of the last matrix, in order to obtain the priority vector column that represents the weights for the criteria.
4-Calculating the value of the weighted sum column: It is calculated by multiplying the priority vector column W_c by each row of the matrix (except the sum row).
5-Calculating (λ_{max}): We do this step by dividing the weighted column values by each corresponding value of the priority vector column, then we add the resulting numbers and divide them on their count.
6-Then the consistency index (C.I) is calculated by subtracting the value of λ_{MAX} from the number of criteria and then dividing it by the number of criteria minus one, according to the following law:

$$C.I = \frac{\lambda_{MAX} - n}{n - 1}$$

7- The consistency ratio (CR), which is the numerical indicator for measuring the consistency of the pairwise comparison matrix, is calculated by dividing the consistency index (C.I) by the average consistency index (RI) as follows: $CR = \frac{CI}{RI}$

The consistency ratio is designed to demonstrate the degree of consistency of opinions in pairwise comparisons. If CR < 0.1, experts' opinions are consistent, while if CR > 0.1, opinions are inconsistent. Note that the value of Ri, as mentioned by Al-Saati, depends on the number of criteria (n). The results obtained from calculating the consistency ratio can be summarized in the following table:

Table (3): Summary of consistency ratio calculations

NO	Aggregate Matrix comparison	CR	The result
1	Main criteria	0.036	consistent
2	Safety Sub-criteria	0.066	consistent
3	business interruption loss sub-criteria	0.046	consistent
4	technical feasibility sub-criteria	0.011	consistent
5	Comparison of alternatives according to personal safety	0.090	consistent
6	Comparison of alternatives according to the facility safety	0.061	consistent
7	Comparison of alternatives according to the environmental safety	0.043	consistent
8	Comparison of alternatives according to spare parts inventory	0.032	consistent
9	Comparison of alternatives according to the production loss	0.044	consistent
10	Comparison of alternatives according to quality	0.034	consistent
11	Comparison of alternatives according to reliability	0.021	consistent
12	Comparison of alternatives according to the applicability	0.022	consistent

6- Determine the relative importance of the main and sub-criteria:

The relative importance of the main and sub-criteria can be calculated through the following steps:

1-We calculate the arithmetic mean for each criteria with fuzzy values, according to the following law:

$$\tilde{r}_i = \left[\prod_{j=1}^{n} \tilde{d}_{ij}\right]^{\frac{1}{n}}$$

2-Find the sum of each column of values resulting from the previous point. Then find the inverse of each sum by raising it to the power of (-1). Then arrange the inverse of the sum in a new row in ascending order.

3-Obtain the fuzzy weights by multiplying each value of $\tilde{r}_i$ with the value of the inverse of the sum, arranged in ascending order according to each column, as in the following equation:

$$\widetilde{w} = \tilde{r}_i * (\tilde{r}_1 + \tilde{r}_2 + \cdots + \tilde{r}_n)^{-1}$$

4-Removing the fuzzification by calculating the average of the triangular fuzzy weights for each row, as in the following equation:

$$M_i = \frac{(lmi + mwi + umi)}{3}$$

5-Normalization by collecting the values of M_i and then dividing each value by its sum, as in the following equation: $N_i = \frac{M_i}{\sum_{i=1}^{n} M_i}$

By performing the same steps and calculations previously applied to all criteria, the weights for the main and sub-criteria were extracted, which are explained in the following tables. Initially, the weights for the main criteria were extracted to determine which were most important to the station engineers. The results were as follows:

Table (4): Relative weights of the main criteria

NO	Main-criteria	Weight in FAHP
1	Safety	0.337
2	business interruption loss	0.104
3	technical feasibility	0.559

Then the relative importance of the sub-criteria was extracted. The result was as follows:

Table (5): Relative weights of sub-criteria

NO	criteria	N_i
1	personal safety	0.160
2	facility safety	0.465
3	environmental safety	0.375
4	spare parts inventory	0.192
5	production loss	0.106
6	quality	0.702
7	reliability	0.302
8	applicability	0.698

7- We calculate the global weights by multiplying the weight of each main criterion by the weights of its sub-criteria. Using the above data, we can extract the global weights of the criteria, as follows:

Table (6): Global Weights

Main-criteria	Main-criteria weights	Sub-criteria	Sub-criteria weights	Global weights
Safety	0.337	personal safety	0.160	0.054
		facility safety	0.465	0.157
		environmental safety	0.375	0.126
business interruption loss	0.104	spare parts inventory	0.192	0.020
		production loss	0.106	0.011
		quality	0.702	0.073
technical feasibility	0.559	reliability	0.302	0.169
		applicability	0.698	0.390

The maintenance alternatives were then compared, each time according to a specific criterion. This resulted in the relative weights for each alternative and for each of the criteria by which the alternatives were evaluated. The relative weights obtained for each alternative and the global weight for each criterion are shown in the following table:

Table (7): Relative weights for each alternative

NO	Alternatives/Criteria	personal safety (0.054)	facility safety (0.157)	environmental safety (0.126)	spare parts inventory (0.020)	production loss (0.011)	Quality (0.073)	Reliability (0.169)	Applicability (0.390)
1	**Corrective Maintenance**	0.090	0.140	0.078	0.276	0.305	0.089	0.069	0.184
2	**time-based preventive maintenance)**	0.454	0.495	0.437	0.391	0.462	0.388	0.405	0.309
3	**Condition-Based Maintenance**	0.398	0.270	0.352	0.262	0.177	0.331	0.327	0.309
4	**Predictive maintenance**	0.058	0.094	0.132	0.071	0.057	0.192	0.198	0.198

Since we know the global weights and the weights of the alternatives against each criteria, we can now extract the total weight for each alternative and then rank the alternatives according to their importance (priority), as follows:

Table (8): Relative weights of alternatives multiplied by global weights

NO	Alternatives/Criteria	personal safety	facility safety	environmental safety	spare parts inventory	production loss	Quality	Reliability	Applicability
1	**Corrective Maintenance**	0.005	0.022	0.010	0.006	0.003	0.006	0.012	0.072
2	**time-based**	0.024	0.07	0.055	0.008	0.005	0.028	0.068	0.121

	preventive maintenance)		8						
3	**Condition-Based Maintenance**	0.021	0.042	0.044	0.005	0.002	0.024	0.055	0.121
4	**Predictive maintenance**	0.003	0.015	0.017	0.001	0.001	0.014	0.033	0.077

When the weights in each row are added together, we obtain the total weight for each alternative, which is shown in the following table:

Table (9): Ranking of alternatives

NO	Alternatives	Total weight	Rank
1	Corrective Maintenance	0.135	4
2	time-based preventive maintenance)	0.387	1
3	Condition-Based Maintenance	0.315	2
4	Predictive maintenance	0.161	3

The previous table shows that time-based preventive maintenance has the highest priority, having received a weight equal to (0.387). Condition-based maintenance then received the second highest priority, having received a weight equal to (0.315). The third highest priority was for predictive maintenance, which received a weight of (0.161). Corrective maintenance received the lowest weight and priority, which was equal to (0.135).

7-Conclusions:

In the literature on maintenance strategy selection, the FAHP is the most widely used tool in this field to find a solution to the problem of selecting a maintenance strategy. This is due to its ability to express the desires of stakeholders and find a solution to a problem with multiple, even conflicting, criteria.

The results show that the highest priority criteria for the company's engineers is the applicability criterion, with a weight of 0.390. The second criterion is reliability, with a weight of 0.169. The third criterion is facility safety, with a weight of 0.157. The fourth criterion is environmental safety, with a weight of 0.126. The remaining weights follow.

As we can see from the results, time-based maintenance is the most preferred maintenance strategy by the company's engineers, receiving a total weight of 0.387. This is because it is the maintenance method applied at the power plant. General Electric has set the periodic maintenance schedules for the plant. Most plant engineers rely on this strategy because of the flexibility it provides. This allows them to ensure the plant's continued operation after maintenance is performed. This demonstrates the true ability of the FAHP tool to express stakeholders' desires and find a solution that satisfies their needs. Condition-based maintenance was the second most important strategy, receiving a weight of 0.315. This strategy can be relied upon to maintain equipment before it reaches the point of complete failure. It relies on sensors or even the sense of hearing to identify a problem and address it before it escalates. This is reflected in the criteria values. In all criteria, especially in reliability, production loss, personal safety, and facility safety, this strategy outperformed the predictive and corrective strategies.

Predictive maintenance also received the third highest weight (0.161), which is higher than corrective maintenance, which received a weight of (0.135). This may be due to the fact that predictive maintenance provides a better ability to identify faults before they occur and address them before equipment failure occurs. This provides a greater degree of assurance of plant continuity and higher reliability. This was expressed by predictive maintenance receiving a higher weight in the reliability and facility safety criteria compared to corrective maintenance. The fact that predictive maintenance received a lower weight than time-based and condition-based maintenance may also reflect concerns about implementing a new strategy whose results may be less than expected.

The results obtained indicate that time-based preventive maintenance is preferred as the primary maintenance strategy applied at the plant. However, the results also indicate potential for improvement. Therefore, we recommend expanding the application of condition-based maintenance and establishing specific policies for it. We also recommend implementing predictive maintenance, especially for equipment whose breakdown schedules can be predicted, and reducing reliance on corrective maintenance. This also depends on the choice of decision makers at the plant, by determining the number of strategies they wish to implement. It is worth noting that implementing predictive maintenance requires the provision of specialized equipment and software to implement this strategy, in addition to providing training for the maintenance staff to handle it. Condition-based maintenance, on the other hand, requires fewer additional costs and requirements. Here, the obstacle to implementing predictive maintenance is the additional costs that must be incurred to implement this strategy.

From the results obtained, we conclude the effectiveness of the Fuzzy Analytical Hierarchy Process (FAHP) tool in solving multi-criteria decision-making problems. The results demonstrated the tool's ability to find a solution to a problem, even if the problem relies on qualitative criteria. It provides a systematic method for assigning weight to each criterion, which then helps in finding a solution that reflects the needs of decision makers and, consequently, satisfies them.

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