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Abstract. The aim of this paper is to develop a multi-criteria decision making based on the Fuzzy Analytical Hierarchy Process (Fuzzy AHP) to select the best maintenance strategy for a spinning mill industry. The maintenance process can enhance reliability, quality of the products, cost, and other aspects. Therefore, the selection of appropriate maintenance strategies is a critical issue for manufacturers. Fuzzy AHP approach is proposed as the selection problem includes uncertainties and difficulty in evaluating alternatives and criteria with definite expressions. The process of decision making involves the comparison of three alternatives of feasible maintenance strategy which are corrective maintenance, periodic maintenance, and predictive maintenance. Each alternative is evaluated against criteria according to the priorities of the decision-makers. The criteria are feasibility, cost, reliability, safety and production quality. The result shows that reliability is the most important criterion with the weight of 0.309, followed by safety (0.235), quality (0.193), cost (0.190), and feasibility (0.074). Periodic maintenance has the highest alternative with a total score of 0.423 and it is ranked first, predictive maintenance is ranked second with a score of 0.355, and corrective maintenance has the lowest rank with a score of 0.222. According to the results, periodic maintenance is chosen as the best maintenance strategy. Finally, the proposed method is successfully applicable in maintenance strategy selection.

1. Introduction

In today's competitive manufacturing environment, maintenance plays a significant role in production activities. Maintenance is the set of all activities meant to keep a system into a condition where it can perform its function [1]. Machine failure may cause various business problems such as failure to meet delivery dates, poor product quality, loss of industrial reputation, loss of profit and opportunity [2]. The selection of appropriate maintenance strategies is an important task for a manufacturing firm as a maintenance strategy can highly affect the manufacturing expenditures. Maintenance costs can reach 15 to 70 percent of total production costs, varying according to the type of industry [3].

A large number of studies have been devoted to select a maintenance strategy. In the literature, Muinde *et al* proposed the Analytical Hierarchy Process (AHP) for selecting maintenance strategy in the cement industry [2], while Bevilacqua and Braglia have described an application of AHP for selecting best maintenance strategy in an oil refinery industry [3]. Shyjith *et al* and Kirubakaran described the use of a combination of AHP and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to select an optimum maintenance strategy [4,5]. Narges Hemmati *et al* proposed a fuzzy-ANP approach [6] while Mahdi Bashiri *et al* proposed a fuzzy interactive linear assignment method for selecting maintenance strategy [7].

The purpose of this paper is to focus on the use of Fuzzy Analytic Hierarchy Process (Fuzzy AHP) method to select the best maintenance strategy for a spinning mill company and help decision-makers to select the best one. Fuzzy AHP is the extension of the Analytic Hierarchy Process. By using Fuzzy AHP, the uncertainty and imprecision associated with the decision maker's perception in the conventional Analytic Hierarchy Process can be reduced.

2. Method

Fuzzy Analytic Hierarchy Process (Fuzzy AHP) method is the combination of the Analytic Hierarchy Process (AHP) and the fuzzy set theory. The Analytic Hierarchy Process (AHP) was firstly proposed by Thomas Saaty [8] has been widely used to solve various multiple criteria decision-making problems. However, due to vagueness and uncertainty in the decision maker's judgment, AHP may be unable to accurately capture the decision maker's judgment. Therefore, fuzzy logic is introduced to reduce the vagueness and uncertainty in conventional AHP and to give a more accurate description of the decision-making process [9].

Fuzzy AHP has been widely applied in the various field for solving Multi Criteria Decision Making problems. For example, Fuzzy AHP was applied for the evaluation and selection of a supplier for a gear motor company [10], for the selection of alternative concepts in the conceptual design phase [11,12], etc. In Fuzzy AHP the linguistic variables used for the judgment of comparison values are expressed into fuzzy numbers. Linguistic variables are variables whose values are not numbers but words or sentences from a natural language. A linguistic variable is generally decomposed into a set of linguistic terms (e.g low, high). Fuzzy numbers are a fuzzy subset of real numbers, representing the expansion of the idea of the confidence interval [13]. In this study for computational simplicity, triangular fuzzy numbers are adopted to characterize the membership function. Triangular fuzzy numbers can be denoted by $\tilde{A} = (l, m, u)$, where l, m and u stands for lower, middle and upper value, respectively, of the fuzzy number $\tilde{A}$.

A fuzzy number $\tilde{A}$ on R would be triangular fuzzy numbers if its membership function $\mu_{\tilde{A}}(x): R \rightarrow [0,1]$ is equal to: [13]

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

2.1. The steps of Fuzzy AHP

The steps of Fuzzy AHP for selection maintenance strategy are as follows:

Step 1: Forming a committee of decision-makers
A committee of decision-makers from the staff of the company is formed.

Step 2: Determining selection criteria and the alternative maintenance strategies
The decision-makers determine the alternative maintenance strategies and the selection criteria

Step 3: Constructing hierarchy structure
At this step, the decision problem is decomposed into a hierarchy. The top-level of the hierarchy represents the overall goal that is to choose the best maintenance strategy, the intermediate level represents the selection criteria affecting the decision, and the bottom level represents the alternative strategies.

Step 4: Identifying linguistic variables
The linguistic term and linguistic variable are expressed using a triangular membership function. The linguistic terms and corresponding triangular fuzzy numbers are given in Table 1 [10]

Step 5: Comparing the selection criteria or alternative strategy
Decision-makers compare the selection criteria via linguistic terms shown in Table 1.

Table 1. Linguistic terms and triangular fuzzy number

Saaty's scale	Linguistic terms	Triangular fuzzy numbers
1	Equally important	(1,1,1)
3	Moderately important	(2,3,4)
5	Strongly important	(4,5,6)
7	Very Strongly important	(6,7,8)
9	Extremely important	(9,9,9)
2		(1,2,3)
4	Intermediate values	(3,4,5)
6		(5,6,7)
7		(7,8,9)

Step 6: Constructing pairwise comparison matrix
Pairwise comparison matrix $\tilde{A}^k$ is shown in equation (2), $\tilde{a}_{ij}^k$ indicates the kth decision maker's preference of ith criterion over j^{th} criterion via triangular fuzzy numbers [10].

$$\tilde{A}^k = \begin{bmatrix} \tilde{a}_{11}^k & \tilde{a}_{12}^k \cdots & \tilde{a}_{1n}^k \\ \tilde{a}_{21}^k & \tilde{a}_{22}^k \cdots & \tilde{a}_{2n}^k \\ \vdots & \vdots & \vdots \\ \tilde{a}_{n1}^k & \tilde{a}_{n2}^k & \tilde{a}_{nn}^k \end{bmatrix} \qquad (2)$$

Step 7: Aggregating of group decisions
For aggregating group decisions, the geometric mean is used as equation (3):

$$l_{ij} = \left(\prod_{k=1}^{K} l_{ijk}\right)^{1/K}, m_{ij} = \left(\prod_{k=1}^{K} m_{ijk}\right)^{1/K}, u_{ij} = \left(\prod_{k=1}^{K} u_{ijk}\right)^{1/K} \qquad (3)$$

where ($l_{ijk}, m_{ijk}, u_{ijk}$) is the fuzzy evaluation of decision-makers k (k=1,2,3,....,K)

Step 8: Updating pairwise comparison matrix
New pairwise comparison matrix is obtained as equation (4)

$$\tilde{A} = \begin{bmatrix} \tilde{a}_{11} & \tilde{a}_{12} \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & \tilde{a}_{22} \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \tilde{a}_{nn} \end{bmatrix} \qquad (4)$$

Step 9: Calculating fuzzy weight of criteria
The fuzzy weight matrix is calculated by Buckley's geometric mean method [14]
The geometric mean of fuzzy can be calculated by using equation (5):

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{a}_{ij}\right)^{\frac{1}{n}} , \text{ for all } i \qquad (5)$$

Where $\tilde{r}_i$ is the geometric mean of fuzzy comparison values of criterion i to each criterion.

Fuzzy weight $\widetilde{w}_i$ of the ith criterion indicated by a triangular fuzzy number is as follows :

$$\widetilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \ldots \oplus \tilde{r}_n)^{-1} \qquad , i = 1,2, \ldots, n \tag{6}$$

$$\widetilde{w}_i = (lw_i, mw_i, uw_i)$$

Where lw_i, mw_i, uw_i stands for the lower, middle, and upper values of the fuzzy weight of the ith criterion.

Step 10: Defuzzyfication

Since fuzzy weight, $\widetilde{w}_i$ are still fuzzy numbers, $\widetilde{w}_i$ has to be defuzzified into crips numbers by using the Center of Area method as follows :

$$w_i = \frac{l\widetilde{w}_i + m\widetilde{w}_i + u\widetilde{w}_i}{3} \qquad , i = 1,2,3,\ldots,n \tag{7}$$

Step 11: Normalization of non fuzzy number

The non fuzzy weights w_i have to normalized by using equations (8) :

$$W_i = \frac{w_i}{\sum_{i=1}^n w_i} \tag{8}$$

Where W_i represents normalized weight of the ith criterion

Step 12: Checking consistency of the comparison matrix

To check the consistency of the comparison matrix, the consistency rate (CR) has to be calculated. The CR is defined as a ratio between the consistency of a consistency index (CI) and the consistency of a random consistency index (RI). The Consistency Ratio (CR) is calculated by using the formula as in equation (9) and the value of CR should not exceed 0.1 [8]. The RI values for the different number of criteria are shown in Table 2.

$$CR = \frac{CI}{RI} \tag{9}$$

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

Where: λ_{max} is eigen vector and n is the number of criterion

Table 2. Random Index (RI) values for n number of criterion

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.58

Step 13: Calculating the weight of alternatives

At this step, the alternative maintenance strategies are compared among others with respect to each selection criteria. To find the weight of alternatives, similar procedures to that described in step 5 to step 12 are performed.

Step 14: Calculating the total score and ranking the alternatives

The total score for each alternative is calculated by using equation (11)

$$S_j = \sum_{i=1}^n WC_{ij} W_i \tag{11}$$

Where : WC_{ij} = weight of alternative j for the ith criterion, W_i = weight for ith criterion, n = number of criteria, S_j = total score of alternative j.

Finally, each alternative is given a rank corresponding to its total score.

3. Result and Discussion

PT XYZ is one of the yarn spinning company and is located in Bandung, Indonesia. The maintenance manager of the company feels that the current maintenance strategy is not efficient to fulfill the company's present objectives, hence the maintenance manager considered to perform the appropriate maintenance strategy for the next company's maintenance strategy. The complexity of manufacturing systems makes it difficult to decide about maintenance strategy, therefore a well-designed decision process is needed to help managers on minimizing decision failures. In this study, the Fuzzy AHP method is proposed for solving the manager's problem.

Five selection criteria and three alternatives of maintenance strategies were determined by decision-makers on the company. The selection criteria are:

a. Feasibility, refers to the acceptance of workers of the strategy socially and professionally. Feasibility criterion includes the efficiency strategy to perform the task effectively and the accessibility to the technology required [15].

b. Cost, refers labor cost, training cost, spare parts and hardware cost

c. Reliability, means the ability of the strategy to preserve significant items within the facility, maximize the time between failures, provide inspections with no diagnostic errors, keep all equipment and machine accessible for inspections, and implement reliable techniques [15].

d. Safety, includes human safety, environment safety, machine, and facility safety.

e. Production quality refers to the ability of the strategy to increase production quality.

The alternative to maintenance strategies are:

a. Corrective Maintenance (CRM)

   The definition of Corrective Maintenance according to the standard PrEN13306: Maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function [16].

b. Periodic Maintenance (PRM)

   In Periodic maintenance or Time-based maintenance, decisions (e.g., preventive repair times/intervals) are determined based on failure time analyses. The aging of some equipment is estimated based on failure time data or used based data. Periodic maintenance assumes that the failure (characteristic) of equipment can be predicted by the time [17].

c. Predictive Maintenance (PDM)

   The definition of Predictive Maintenance according to the standard PrEN13306: Condition based maintenance carried out following a forecast derived from the analysis and evaluation of significant parameters of the degradation of the item. Predictive maintenance is performed continuously or at intervals according to the requirements to diagnose and monitor a condition or system [16].

To decompose the decision problems of choosing the best maintenance strategy, three levels of hierarchy structure is constructed as shown in Figure 1.
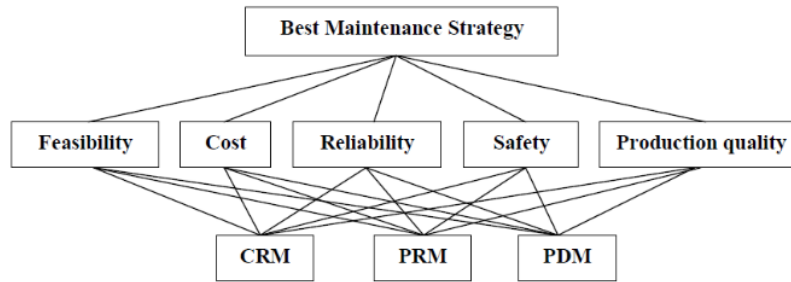
Figure 1. Hierarchy structure

During the decision process, decision-makers compare the selection criteria by using the linguistic variable and corresponding triangular fuzzy number as is shown in Table 1. After doing constructing pairwise comparison matrix, calculating the fuzzy weight of criteria, defuzzyfication, and normalization of the nonfuzzy number, the weight of each criterion can be found. The level of inconsistency in the comparison matrix is acceptable as the value of consistency ratio (CR) is less than 0.1. To find the weight of alternatives CRM, PRM, PDM are compared among others with respect to each selection criteria and the procedures are similar to that described in step 5 to step 12. Finally, the total score and the rank of each alternative can be obtained. The weight of each criterion, the weight of alternatives with respect to each criterion, total score, and rank of each alternative are tabulated as shown in Table 3.

Table 3. Final result

Criteria	Weight of criteria, W	Weight of alternative maintenance strategy, WC		
		CRM	PRM	PDM
Feasibility	0.074	0.765	0.108	0.126
Cost	0.190	0.339	0.331	0.331
Reliability	0.309	0.124	0.469	0.407
Safety	0.235	0.101	0.514	0.386
Production quality	0.193	0.203	0.451	0.346
Total score, S_j		0.222	0.423	0.355
Rank		3rd	1st	2nd

Table 3 shows that the reliability criterion has a weight of 0.309, safety 0.235, production quality 0.193, cost 0.190, and feasibility 0.074. Also, it can be seen from Table 3 that Periodic Maintenance (PRM) has obtained the highest total score among three alternatives with a total score of 0.423 and PRM is ranked first. Predictive maintenance (PDM) and Corrective maintenance (CRM) have obtained at the second and third rank with 0.355 and 0.222. Based on the final results, Periodic Maintenance is selected as the best maintenance strategy for the company.

4. Conclusion
Maintenance plays a significant role in production activities. An appropriate maintenance strategy can improve the availability of production equipment and avoid unnecessary expenditures in maintenance. Selection of appropriate maintenance strategy is a crucial task for the company, therefore it needs multi criteria decision making to evaluate the strategies. In this paper, the Fuzzy AHP method was proposed for the evaluation and selection of the best maintenance strategy for a spinning mill company. Fuzzy AHP was used for reducing the vagueness and uncertainty of the decision maker's judgment. Three alternatives of maintenance strategies were to be considered and evaluated with

respect to five criteria. Finally, this paper shows that Fuzzy AHP is successfully applicable as an evaluation technique for the maintenance strategy selection problem.

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