ISBN - 978-989-9121-08-9
43rd PATTAYA International Conference on "Advances in Science, Engineering & Information Technology" (PASEIT-22)
Pattaya (Thailand) Aug. 25-26, 2022

Multi-Criteria Maintenance Technique Selection using Fuzzy Analytic Hierarchy Process

Wirunpuch Prommachan[1], Prayoon Surin[1], Pramot Srinoi[2] and Manop Pipathattakul[3]

[1]Department of Advanced Manufacturing Technology, Pathumwan Institute of Technology, Bangkok, Thailand
[2]Department of Industrial Engineering, Kasem Bundit University, Bangkok, Thailand
[3]Department of Mechanical Engineering, Pathumwan Institute of Technology, Bangkok, Thailand

Abstract: *The ultimate goal of all organizations was to keep the machinery up and running at all times, requiring good maintenance to minimize downtime and maximize efficiency. This usually posed problems to the decision-maker and due to diversity in proficiency level, decision-making was ambiguous, resulting in uncertainty. This work aimed to propose a guideline for decision-making tool development to assess maintenance techniques for rotating machinery. This studied case used a method based on analytic hierarchy process and fuzzy number, called Fuzzy Analytic Hierarchy Process (Fuzzy AHP) to support the decision-making process. Five factors were used for assessment of rotating machinery maintenance technique: Vibration analysis, Acoustic emission analysis, Oil analysis, Infrared thermography, and Wear particle analysis. The analyzed data was obtained from experts in maintenance technique selection. The study revealed that the Fuzzy AHP was suitable for systematic decision-making process, and was able to propose appropriate choices.*

Keywords: *Fuzzy Analytic Hierarchy Process; Maintenance Technique; Rotating Machinery*

1. Introduction

Maintenance is a critical process that needed to be well-managed. The first step of machinery management is selecting the best strategy to optimize machinery maintenance, which cannot simply be ignored. Maintenance can be divided into many types such as preventive maintenance, predictive maintenance, and corrective maintenance. R. Baidya et al. (2015) found that maintenance would reduce damage to all the machinery in the factory and ensure that the repaired machinery would be in an acceptable state. W. Hongxia et al. (2016) found that maintenance would allow analysis and correction of the machinery problem before it grew into a severe problem. Early repairs would maximize lifespan of the machinery and decrease the chance of machinery malfunction. The machinery requires maintenance to keep it in the optimal condition and efficiency. Any ambiguity in the decision-making process might result in incorrect decision. Therefore, the Fuzzy AHP, deemed a tool capable of assisting in decision-making process, was brought into the study. The Fuzzy AHP was born from combining the fuzzy number theory and Analytic Hierarchy Process (AHP).

Fuzzy AHP has gained wider acceptance and is used by many researchers to improve the competitiveness. Regarding production cost-cutting, M. Weck et al. (1997) used Fuzzy AHP to assess different cost-cutting choices of the production process using multivariate analysis. About cost assessment, A. K. Mason et al. (1998) used AHP in conjunction with fuzzy principles to assess cost, using data from cost assessment experts that usually had uncertainty in decision making. Regarding supplier assessment, K. Cengiz et al. (2003) improved the supplier selection principle by assessing reputation, product quality and service quality using Fuzzy AHP. Regarding selection of service provider, L. Mikhailov et al. (2004) proposed a guideline for uncertainty management using fuzzy number sequencing and hierarchic comparison of AHP to select the service provider, using three factors: price, service quality, and delivery time. On the other hand, there was strategy assessment by

D. Orlando Duran et al. (2008) that used six criteria for economic and strategic assessment: flexibility, ease of use, reliability, quality, success probability and maintenance for selection of industrial machinery to improve competitiveness. This approach used AHP and Fuzzy to help assess.

Literature review showed that the Fuzzy AHP could help with decision making process to be more systematic and was capable of improving the decision-making process.

2. Research Methodology

The process of obtaining suitable criteria for selecting a maintenance technique can be accomplished by researching relevant research data. Then a questionnaire was prepared for experts to analyze the importance of each factor. A. Abdel Khalek et al. (2018) and M. Balubaid et al. (2015) had the experts answered a questionnaire to analyze the importance of each criterion for the solution of each component. S. N. F. Zuraidi et al. (2018) used the questionnaire was developed based on criteria and appropriateness [18]. Twenty experts participated in this research: 2 management engineers, 10 maintenance engineers and 8 repair technicians. This set of criteria is provided courtesy of industry experts. The concept of each criterion can be summarized as follows:

a) Oil analysis can be used to indicate the performance or condition of machinery and equipment. Deterioration of lubricants and various contaminants

b) Acoustic emission analysis can be used to monitor material damage in action by detecting energy in the form of transient elastic waves that emit a signal from material defects.

c) Wear particle analysis can be used to study debris falling into a sample of lubricant. This analysis provides direct information on machine wear conditions.

d) Infrared thermography can be used to create images using infrared (IR) radiation instead of IR light, not visible to the naked eye. but being emitted or reflected by any object or being heating

e) Vibration analysis can be used to indicate various types of malfunctions of rotating machinery such as unbalance, shaft misalignment, looseness, bearing malfunction, gear malfunction, resonance frequency, belt malfunction, electrical problem, and other problems.

3. Fuzzy AHP Analysis

A reasonable decision depended on a reasonable decision-making process. Factors used in the analysis had to be connected, and comparative analysis of factors needed consistency of reasons. Details on the AHP process could be shown below.

1. The scope has to be on-point, and the decision-making and choice criteria has to be appropriate.
2. Set up a hierarchical graph of components obtained in the previous step through brainstorming, starting from the top, like the goal, main criteria and choice, as shown in Figure 1.

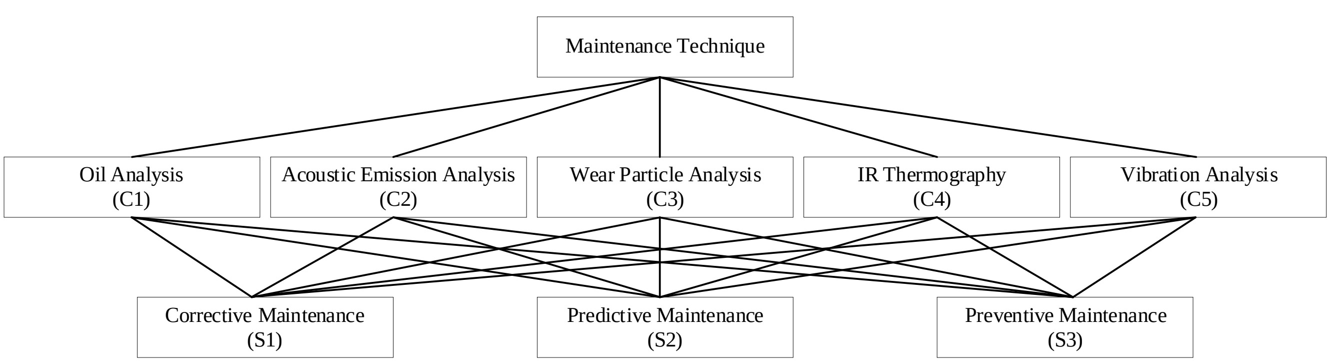

Fig 1. Fuzzy Analytic Hierarchy Process Structure

3. Build a matrix to analyze factors in a pairwise, fuzzy fashion to determine the effect of each factor on the criteria or factor in the higher level as shown in Table 1.

TABLE I. Fuzzy Comparison Matrix for Criteria

Criteria	**Oil Analysis**	**Acoustic Emission Analysis**	**Wear Particle Analysis**	**IR Thermography**	**Vibration Analysis**
Oil Analysis	(1.00, 1.00, 1.00)	(0.50, 0.33, 0.25)	(4.00, 5.00, 6.00)	(4.00, 5.00, 6.00)	(0.25, 0.20, 0.17)
Acoustic Emission Analysis	(2.00, 3.00, 4.00)	(1.00, 1.00, 1.00)	(6.00, 7.00, 8.00)	(6.00, 7.00, 8.00)	(0.50, 0.33, 0.25)
Wear Particle Analysis	(0.25, 0.20, 0.17)	(0.17, 0.14, 0.13)	(1.00, 1.00, 1.00)	(0.17, 0.14, 0.13)	(0.17, 0.14, 0.13)
IR Thermography	(0.25, 0.20, 0.17)	(0.17, 0.14, 0.13)	(0.17, 0.14, 0.13)	(1.00, 1.00, 1.00)	(0.17, 0.14, 0.13)
Vibration Analysis	(4.00, 5.00, 6.00)	(2.00, 3.00, 4.00)	(6.00, 7.00, 8.00)	(6.00, 7.00, 8.00)	(1.00, 1.00, 1.00)

Fuzzy AHP was applied by Van Laarhoven et al. (1983), the fuzzy data was represented as Triangular fuzzy member or as called membership of elements. Later Zheng et. al. (2012) found development into other forms like Trapezoidal, Bell-shape or Gaussian as shown in Fig 2. This work used Triangular fuzzy member which was widely-used.

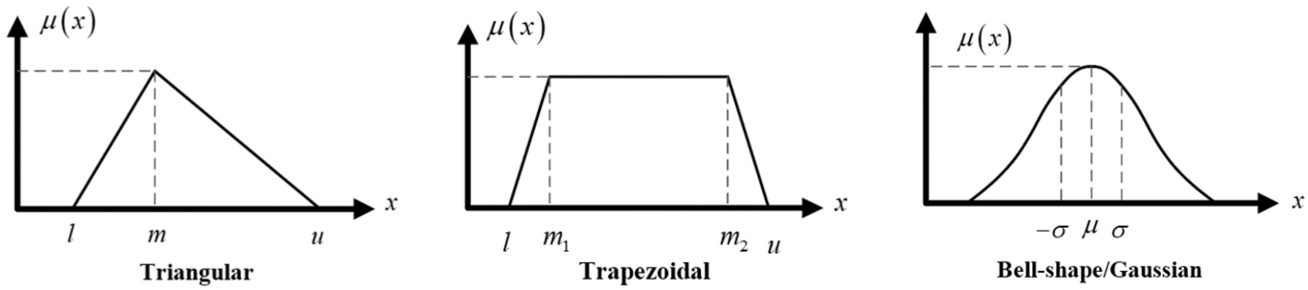

Fig 2. Traditional Membership Function used in Fuzzy AHP

4. After inputting the comparative analysis numbers into the matrix, importance level was calculated by reducing fuzziness from the decision-maker's choice analysis. Using the fuzzy number for calculation in conjunction with the AHP at this point included assignment of importance level, and the logic of which was shown in the triangular form because it was easier to understand, and could be calculated using the triangular fuzzy member and pairwise comparison of AHP. The importance level, in the form of Fuzzy AHP for comparison with the AHP could be shown in Table 2.

TABLE II Membership Functions of Fuzzy AHP

Linguistic Variable	**Explanation**	**Fuzzy No.**
Equally Important	Activities contribute equally to the objective	(1,1,1)
Slightly Important	Judgement slightly inferior tone criterion to another	(2,3,4)
Strong Important	Judgement strongly inferior tone criterion to another	(4,5,6)
Very strong Important	Judgement slightly favor one criterion over another	(6,7,8)
Absolute Important	Judgement strongly favor one criterion over another	(8,9,10)

The weight of factors was calculated from fuzzy synthetic boundary (Equation 1), probability (Equation 2) importance vector (Equation 3) and weight of factor (Equation 4).

Synthetic fuzzy boundary (S_i) $$S_i = \sum_{j=1}^{m} M_{gj}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \quad (1)$$

Probability of $S_i \geq S_j$ when $S_i = \left(l_i, m_i, u_i\right)$, $S_j = \left(l_j, m_j, u_j\right)$; $i \neq j$ as shown in Equation 2

$$V(S_i \geq S_j) = \begin{cases} 1, & m_i \geq m_j \\ 0, & l_j \geq u_i \\ \dfrac{(l_i - u_i)}{(m_i - u_i) - (m_j - l_j)}, & Other \end{cases} \tag{2}$$

Importance vector was calculated by the following Equation

$$W_i^{'} = \min V(S_i \geq S_j \; j = 1, 2, ..., m; i \neq j) \tag{3}$$

Importance of i[th] factors from 1 to n was

$$W_i = \frac{W_i^{'}}{\sum_{i=1}^{n} W_i^{'}} \tag{4}$$

5. Proceed with Steps 3, 4 and 5 for factors in each layer of the hierarchy.
6. Synthesize all components of the graph, using importance of lower factors to weigh against importance of factors in the next higher level. Then, the sum is calculated for importance value across the entire graph. Repeat until the lowest level. That is the level of choice.
7. Arrange all choices in order and select the best one.

TABLE III Geometric means, Fuzzy & Normalized Weight of Criteria

Criteria	**Geometric Means**	**Fuzzy Weight**	**Normalized Weight**
Cl	(0.82, 0.95, 1.15)	(0.13, 0.19, 0.27)	0.189
C2	(0.82, 0.95, 1.12)	(0.13, 0.19, 0.27)	0.187
C3	(0.78, 0.87, 1.00)	(0.13, 0.17, 0.24)	0.171
C4	(0.70, 0.90, 1.15)	(0.11, 0.18, 0.27)	0.180
C5	(1.06, 1.40, 1.74)	(0.17, 0.28, 0.42)	0.274

The geometric mean of the fuzzy comparative values of each criterion would be calculated, using a tiled Lambda-Max method. After that, the weight of the criterion would be defuzzied with various methods, namely relative fuzzy weight, relative non-fuzzy weight, and normalized weights, result of which are shown in Table 3. Then, the same method would be used to determine technique weight based on the criterion shown in Table 4. The result, combined from results of each technique is shown in Table 5. The result was that out of the three-candidate method, predictive maintenance had the highest overall score, and thus deemed the best technique.

TABLE IV Normalized Non-Fuzzy Relative Weight of each Maintenance and each Criteria

Maintenance	Cl	C2	C3	C4	C5
S1	0.393	0.140	0.250	0.151	0.118
S2	0.275	0.575	0.522	0.425	0.403
S3	0.333	0.284	0.227	0.425	0.479

TABLE V Aggregated Results for each Maintenance According to each Criteria

Criteria	Weights	Scores with respect to related criteria		
		S1	S2	S3
Cl	0.189	0.393	0.275	0.333
C2	0.187	0.140	0.575	0.284
C3	0.171	0.250	0.522	0.227
C4	0.180	0.151	0.425	0.425
C5	0.274	0.118	0.403	0.479
Total		0.203	0.435	0.362

4. Results and Discussion

Fuzzy AHP allowed more realistic and reliable solution for data interpretation in highly complex decision-making processes as it was able to convert specific verbal appreciation into numerical values. The five criteria mentioned was used for determining the best maintenance technique. Task priorities were classified as predictive maintenance (S2) based on the studied case, and the result from the use of Fuzzy AHP revealed that subjectivity related with the human audit result was reduced, and it was a good tool for managers/engineers in decision-making process, and deal with serious equipment failures in a timely manner.

5. Conclusions

Regarding selection of the most appropriate maintenance, the expert usually considers the criteria in a subjective manner, thus planning can be ineffective and inconsistent due to subjective nature of decision-making. As a result, maintenance work efficiency could be greatly affected. A Fuzzy AHP based decision support system is designed for enhancing the planning of maintenance work. The Manager can manage collected data and select the most appropriate technique systematically. It has the ability to handle fuzzy and inaccurate data for efficient planning, so Fuzzy AHP can be applied in real-world situations. In summary, the developed model can provide a clear direction in determining maintenance plans and improving the efficiency of maintenance work.

6. Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The authors would like to thank the editor and anonymous reviewers for their comments that help improve the quality of this work.

References

[1] A. K. Mason & S. Korkmaz. "Obtaining Fuzzy Membership Functions and Rule Sets in Fuzzy Expert Systems with AHP," *Proceedings of the IEEE International Conference on Systems.* (1998) 2315-2319.

[2] D. Orlando & A. Jose. "Computer-Aided Machine-Tool Selection based on a Fuzzy-AHP Approach," *Expert Systems with Applications.* 34-3 (2008) 1787-1794.

https://doi.org/10.1016/j.eswa.2007.01.046

[3] G. Zheng, N. Zhu, Z. Tian, Y. Chen & B. Sun. "Application of a Trapezoidal Fuzzy AHP Method for Work Safety Evaluation and Early Warning Rating of Hot and Humid Environment," *Safety Science.* 50 (2) (2012) 209-217.

https://doi.org/10.1016/j.ssci.2011.08.042

[4] Hesham A. Abdel Khalek, Remon F. Aziz & A. H. Abdeen. "Identify and Prioritize the Major Influencing Causes of Automated Concrete Mixing System for Mega Construction Projects using Analytic Hierarchy Process," *Alexandria Engineering Journal.* 57 (2018) 3451–3461.

https://doi.org/10.1016/j.aej.2018.04.003

[5] K. Cengiz, C. Ufuk & U. Ziya. "Multi-Criteria Supplier Selection using Fuzzy AHP," *Logistics Information Management.* 16 (2003) 382-394.

https://doi.org/10.1108/09576050310503367

[6] L. Mikhailov & P. Tsvetinov. "Evaluation of Services using a Fuzzy Analytic Hierarchy Process,"*Applied Soft Computing.* (2004) 23-33.

https://doi.org/10.1016/j.asoc.2004.04.001

[7] M. Balubaid & R. Alamoudi. "Application of the Analytical Hierarchy Process (AHP) to Multi-Criteria Analysis for Contractor Selection," *American Journal of Industrial & Business Management.* 5 (2015) 581-589.

https://doi.org/10.4236/ajibm.2015.59058

[8] M. Weck, F. Klocke, H. Schell & E. Ruenauver. "Evaluating Alternative Production Cycles using the Extended Fuzzy AHP Method," *European Journal of Operational Research.* 100 (2) (1997) 351–366.

https://doi.org/10.1016/S0377-2217(96)00295-0

[9] P. Van Laarhoven & W. Pedrycz. "A Fuzzy Extension of Saaty's Priority Theory," *Fuzzy and Sets and Systems.* 11(1) (1983) 199-227.

https://doi.org/10.1016/S0165-0114(83)80081-5

[10] R. Baidya & S.K. Ghosh. "Model for a Predictive Maintenance System Effectiveness using the Analytical Hierarchy Process as Analytical Tool," *IFAC-Papers Online.* 48-3 (2015) 1463-1468.

https://doi.org/10.1016/j.ifacol.2015.06.293

[11] S. N. F. Zuraidi & M. A. A. Rahman & Z. A. Akasah. "A Study of using AHP Method to Evaluate the Criteria and Attribute of Defects in Heritage Building," *Proceedings of 11th ICCEE.* during October 12-14 (2018) at Tokyo. Japan.

[12] W. Hongxia, Y. Xiaohui & Y. Ming. Study on "Predictive Maintenance Strategy," *Advanced Science &Technology Letters.* 137 (2016) 52-56.