Selection of Optimal Maintenance Policy by Using Fuzzy Multi Criteria Decision Making Method

Siew-Hong, Ding and Shahrul Kamaruddin
School of Mechanical Engineering
Universiti Sains Malaysia, Nibong tebal, 14300, Penang, Malaysia

Abstract

It becomes important to have a production line with higher productivity to lower the cost since the manufacturing industries are facing greater competitiveness pressure from each others in this globalization era. Maintenance plays an important role in enhancing the productivity. In order to have an effective maintenance, determination of optimal maintenance policy is required. Nevertheless, the decision on the determining the optimal maintenance policy is very crucial; a wrong decision not only lead to the increase of failure rate but also affect the productivity. Thus, an effective method based on integration of fuzzy TOPSIS is proposed for determining the optimal maintenance policy.

Keywords
Fuzzy TOPSIS, multi criteria decision making, maintenance policy

1. Introduction
Manufacturing industry contributes a lot to the development of country's economy. Currently, manufacturing industries are facing significant competitiveness among themselves in globalization era. In order to maintain their competitiveness capability in the market, higher productivity with minimum production cost becomes the main target. Either productivity or production cost, it cannot be apart from maintenance issues. Productivity cannot be achieved without proper maintenance on production system. At the mean time, maintenance expenditure can achieve 15 to 70 percent of production costs in different industry [1]. Practically, maintenance is not an issue that can be eliminated but it can be improved to achieve higher effectiveness of maintenance. The first issue need to be focused in maintenance should be the selection of optimal maintenance policy most suitable for the system. Maintenance policy in this context is a deliberate plan of action to provide guidance for maintenance management in maintenance planning [2]. Therefore, it is important in giving direction and guideline for further maintenance required by a system. It is also been supported by [3], where author stated that doing the right thing is better than doing the thing right. Only with proper maintenance policy, the maintenance of the system can be more effective, furthermore increase the productivity and reduce the production costs.

Nevertheless, it is not an easy matter to determine the optimal maintenance policy due to the certain limitations. The lack of information required for analysis due to the incomplete or non-systematic data management system become one of the main drawback in maintenance policy optimization subject. At the same time, maintenance management seemed does not alert about the existence of available maintenance policies. Their maintenance policy is usually to repair after failure occurs or follow the maintenance instruction provided by system suppliers. The provided maintenance instruction may be inaccurate due to the different operating condition included work load, environmental humidity and temperature. Besides, maintenance policy optimization issue is also a multi criteria decision making topic, where maintenance management need to concern on various issues like safety and workforce available. A systematic analysis method is required to analyze and determine the optimal maintenance policy due to the important role of optimal maintenance policy and its difficulties in determining the optimal maintenance policy. The paper is organized as follow: Section 2 describes the general classification of maintenance policy; Section 3 provides a review of method used in determining the optimal maintenance policy. Section 4 explains the fuzzy linguistic terms used in fuzzy TOPSIS. Section 5 proposes the integration of fuzzy TOPSIS method used to determine the optimal maintenance policy. Section 6 illustrates the application of proposed fuzzy TOPSIS by using a numerical example and finally conclusion in Section 7.

2. Maintenance Policy Classification

Throughout the development of maintenance, many maintenance policies have been proposed and they can be generally classified into four families as shown in Figure 1.

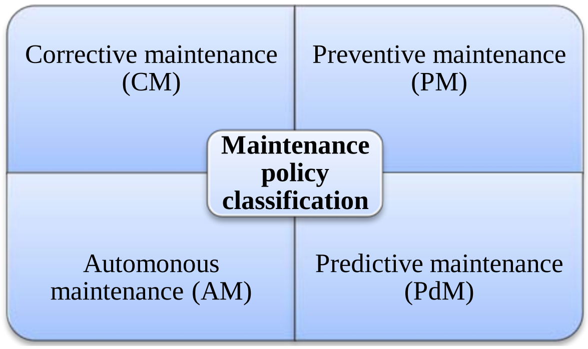

Figure 1: Maintenance policy classification

Corrective maintenance (CM) policy is the oldest maintenance policy among the maintenance policies. CM policy is the original maintenance policy implemented in industry [4]. When CM policy is applied, maintenance will only be carried out after the failure occurs. This policy is considered as a feasible policy to be adopted in the cases where profit margins are large [5]. However, this maintenance policy may cause large production losses, serious damage to the system**,** person and environment due to the unexpected failure. Therefore, in order to reduce the system breakdown and increase utilization, the maintenance responsibility is given to the owner of the system. This policy is known as autonomous maintenance (AM).

AM policy also named as detection based maintenance policy has brought about a maintenance concept where maintenance and production department are working together in conducting the maintenance activities [6]. Maintenance no longer the sole responsibility of maintenance department, persons in the production section also takes part in maintaining the system.

Other than AM policy, preventive maintenance (PM) policy is also a popular maintenance policy. The maintenance under the PM policy is planned and performed after a specified period of time or amount used by the system to reduce the probability of failure. Mechefske and Wang [4] stated that most system is maintained with a significant amount of useful life remaining when PM policy is applied. However, it is difficult to identify the most effective maintenance interval which eventually leads to unnecessary maintenance when lacking of historical data [7]. The alternative to this is the predictive maintenance policy (PdM).

PdM policy is developed due to the growth of technology. Basically, sensors are used to recognize the changes in the condition or performance of a system. The maintenance will be carried out when the system reach the critical point before failure. In other words, the maintenance under the PdM policy is carried out according to the actual condition of the system. Maintenance management can easily and clearly point out an abnormal situation by monitoring the data collected by sensors.

As been discussed, each of the maintenance policy has their special attributes and knowing also that selecting an optimal maintenance policy is not an easy task especially when the production consists of several different systems with different maintenance characteristics [8, 9]. Thus, a lot of efforts have been put in proposing different methods used to determine the optimal maintenance.

3. Literature Review

Due to the significance and the challenges faced in maintenance optimization, a lot of efforts have been done by researchers to assist maintenance management to overcome the stated problems. For example, Bevilacqua and Braglia [10] used analytic hierarchy process (AHP) to select the best possible maintenance policy for systems in oil refinery industry. Authors considered many factors which are important for the selection of the maintenance policy such as economic factors, safety applicability and cost. Ratnayake and Markeset [11] also adopted AHP to determine the optimal maintenance policy in term of health, safety, environment and finance for oil and gas industry. Tan et al. [12] applied AHP to determine the most practicable maintenance policy with different operational functions in oil refinery industry.

There are also fruitful efforts found in integrating MCDM with others different methods like goal programming and fuzzy logic. For instance, Al-Najjar and Alsyouf [13] had integrated weighted sum method (WSM) with fuzzy logic to select the most cost-effective maintenance policy. Bertolini and Bevilacqua [14] implemented the AHP by integrating goal programming to determine the optimal maintenance policy in an oil refinery. The used of the combined methods allowed the authors to investigate the maintenance selection problem in detail, taking into account the resource burden. Jafari et al. [15] proposed WSM with fuzzy Delphi to solve the maintenance policy selection problem. Besides, Shyjith et al. [16] also adopted TOPSIS in identifying the optimal maintenance policy in a textile industry [17]. Also suggested the integration of AHP and goal programming to decide the optimal maintenance in a benzene extraction unit of a chemical plant.

Fuzzy AHP with TOPSIS had been proposed to select the optimal maintenance policy for textile industry [18]. Besides, [19] had introduced an integration of AHP, goal programming with fuzzy logic to determine optimal maintenance policy. The application of proposed combination was performed by using data obtained from [7]. At the same time, another combination of AHP-enhanced TOPSIS and VIKOR had been applied to further improve the effectiveness of maintenance policy decision making in the air craft system [20]. Chen and Chen [21] tried to use AHP, TOPSIS and grey relational analysis to evaluate the performance and decided the optimal maintenance policies that suited semiconductor company in a more effective and accurate manner. TOPSIS with factor analysis had been adopted in maintenance policy selection by considering the feasibility of each policy [22]. Bashiri et al. [23] proposed the fuzzy linear assignment method with the aims to improve the interaction between experts and analytic method in maintenance policy selection problem.

MCDM can take large numbers of criteria into the selection process and improve the overall reliability of the selected maintenance policy while the idea of TOPSIS is based on distance where the chosen option has the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution [24]. The pair wise comparison can be avoided in TOPSIS and the calculation of TOPSIS will not become very complex even though the number of criteria is increases. Furthermore, accuracy of results from TOPSIS can be improved by integration of fuzzy. With the integration of fuzzy, the uncertainty of input data required in TOPSIS can be reduced to minimum. The integration of fuzzy TOPSIS is used to determine the optimal maintenance policy is further discussed in following section.

4. Fuzzy Linguistic Terms

Since policy capability is evaluated based on the expert’s experience which usually very subjective, thus fuzzy TOPSIS can be more suitable to explain how they judge the capability of each maintenance policy to solve the possible failure occurs on the system in terms of linguistic variables. A linguistic variable is a variable which apply words or sentences in a natural or artificial language to describe the degree of value. In this paper, the triangular fuzzy numbers are used to represent the approximate value. The expression used to compare criteria by linguistic variables in a fuzzy environment in this paper is tabulated in Table 1 and 2.

Table 1: Linguistic variables for the importance weigh of each criterion

Linguistic variables	Importance weight of each criterion
Very unimportant	(0.0, 0.0, 0.25)
Unimportant	(0.0, 0.25, 0.5)
Important	(0.25, 0.5, 0.75)
Very important	(0.5, 0.75, 1.0)
Absolutely important	(0.75, 1.0, 1.0)

Table 2: Linguistic variables for the rating of each maintenance policy

Linguistic variables	Importance weight of each criterion
Very low	(1, 1, 3)
Low	(1, 3, 5)
Meduim	(3, 5, 7)
High	(5, 7, 9)
Very high	(7, 9, 9)

5. Fuzzy TOPSIS

Once the linguistic terms are determined, the data required by TOPSIS can be collected and analyzed. The main objective of this selection process is to determine the maintenance policy that can reduce the failures of a system. The capability of maintenance policy to overcome those failures will be evaluated and ranked by using fuzzy TOPSIS. In order to perform fuzzy TOPSIS analysis, a group of decision makers from related field is required. There are two main tasks for decisionnmakers which are evaluate the importance of each criterion and to rate the performance of each alternative (A1, A2,.., Am) against criteria (C1, C2….Cn). Once the rating process is completed, the operational principle of fuzzy TOPSIS is performed in the following steps [25]:

Step 1: Aggregate the importance weights and rating of alternatives performance.
The importance of the criteria and the rating of the alternatives with respect to each criterion acquired from group of decision makers are denoted in Equation (1) and (2):

$$\tilde{x}_{ij} = \frac{1}{K}\sum_{k=1}^{K} \tilde{r}_{ij}^{K} \tag{1}$$

$$\widetilde{w}_j = \frac{1}{K}\sum_{k=1}^{K} \widetilde{w}_j^{K} \tag{2}$$

Where $\tilde{x}_{ij}^{K}$ is the rating of K decision maker and $\widetilde{w}_j^{K}$ are the importance of K decision maker.

Step 2: Formulation of fuzzy decision matrix
The aggregated performance ratings in terms of linguistic variables regarding the selecting m alternative under n different criteria is expressed into fuzzy decision matrix as shown in Equation (3).

$$\widetilde{D} = \begin{array}{c|cccc} & C_1 & C_2 & \dots & C_n \\ \hline A_1 & \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ A_2 & \tilde{x}_{21} & \cdots & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ A_m & \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{array} \tag{3}$$

where, $\widetilde{D}$ represents the fuzzy decision matrix with alternatives A_i (i=1,2,…,m) and the criteria C_j, (j=1,2,…,n). values $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}) \in (\tilde{\beta}_1, \tilde{\beta}_2, \tilde{\beta}_3)$ are linguistic variables that from Equation (1).

Step 3: Fuzzy decision matrix normalization
The linear scale transformation is used to convert the different criteria scales into the range of triangular fuzzy numbers [0, 1].

$$\tilde{r}_{ij} = \begin{cases} \tilde{x}_{ij}(:)x_j^{+} = \left(\frac{a_{ij}}{c_j^{+}}, \frac{b_{ij}}{c_j^{+}}, \frac{c_{ij}}{c_j^{+}}\right), \forall_j, \tilde{x}_j \text{ } is\ a\ benefit\ criterion \\ \tilde{x}_j^{-}(:)\tilde{x}_{ij} = \left(\frac{a_j^{-}}{c_{ij}}, \frac{a_j^{-}}{b_{ij}}, \frac{a_{ij}^{-}}{a_{ij}}\right), \forall_j, \tilde{x}_j \text{ } is\ a\ cost\ criterion \end{cases} \tag{4}$$

Where $\tilde{x}_j^{+} = (a_j^{+}, b_j^{+}, c_j^{+})$and $\tilde{x}_j^{-} = (a_j^{-}, b_j^{-}, c_j^{-})$ represent the highest and the lowest value for each criterion respectively.

The normalized values is organized according to Equation (5).

$$\tilde{R}_{ij} = \begin{bmatrix} \tilde{r}_{11} & \cdots & \tilde{r}_{1n} \\ \vdots & \cdots & \vdots \\ \tilde{r}_{m1} & \cdots & \tilde{r}_{mn} \end{bmatrix} \tag{5}$$

Step 4: Weighted of normalized fuzzy decision matrix.
Considering the different importance weight of each criterion and both normalized valued and weighting are fuzzy numbers.

The weighted normalized fuzzy decision matrix is constructed as:

$$\tilde{v}_{ij} = \tilde{r}_{ij}(.)\tilde{w}_j = \begin{cases} \left(\dfrac{a_{ij}}{c_j^+}\tilde{w}_j, \dfrac{b_{ij}}{c_j^+}\tilde{w}_j, \dfrac{c_{ij}}{c_j^+}\tilde{w}_j\right), \forall_j, \tilde{x}_j \text{ is a benefit criterion} \\ \left(\dfrac{a_j^-}{c_{ij}}\tilde{w}_j, \dfrac{a_j^-}{b_{ij}}\tilde{w}_j, \dfrac{a_{ij}^-}{a_{ij}}\tilde{w}_j\right), \forall_j, \tilde{x}_j \text{ is a cost criterion} \end{cases} \tag{6}$$

The computation of the result can be summarized in matrix formed as follow:

$$\tilde{V} = \begin{bmatrix} \tilde{v}_{11} & \cdots & \tilde{v}_{1n} \\ \vdots & \cdots & \vdots \\ \tilde{v}_{m1} & \cdots & \tilde{v}_{mn} \end{bmatrix} \tag{7}$$

4. The elements in weighted normalized fuzzy decision matrix are normalized positive triangular fuzzy numbers where their range is belong to closed interval [0, 1]. Thus, the positive ideal separation (PIS) and negative ideal separation (NIS) are defined as follow:

$$A^+ = \{\tilde{v}_1^+, \tilde{v}_2^+, \ldots, \tilde{v}_n^+\} \tag{8}$$
$$A^- = \{\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-\} \tag{9}$$

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

5. Separation measurement
The separation distance of each alternative from the PIS and NIS is calculated by using n-dimensional Euclidean distance given as Equation (10) and (11).

$$d_i^+ = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^+), i = 1, 2, \ldots, m \tag{10}$$
$$d_i^- = \sum_{i=1}^{n} d(\tilde{v}_{ij,}\tilde{v}_j^-), i = 1, 2, \ldots, m \tag{11}$$

6. Compute closeness coefficient, *CC* can be adapted as:

$$CC_{\mathrm{i}} = \frac{d_i^-}{d_i^+ + d_i^-}, i=1, 2,\ldots, m \tag{12}$$

The larger the index value means the better the performance of the maintenance policy. Through the analysis by using fuzzy TOPSIS, the maintenance policy with the highest index value calculated using Equation (12) will be proposed as the optimal maintenance policy to the system. The proposed maintenance policy is expected to have the highest effectiveness in reducing the system failures.

6. Numerical Analysis

An example is adopted to demonstrate the application of the fuzzy TOPSIS method in resolving conflicting criteria in determining the optimal maintenance policy for a screw press. Four maintenance alternatives included corrective maintenance (A1), preventive maintenance (A2), predictive maintenance (A3) and autonomous maintenance (A4) is proposed as the potential alternatives in the selection process. Safety (C1), cost (C2), reliability (C3) and feasibility (C4) are four criteria considered as the evaluation criteria for the maintenance policies. A group of 3 decision makers (DMs) has been formed to conduct the assessment based listed criteria and alternatives.

The application of fuzzy TOPSIS method is illustrated according to the following procedure:

Step 1: Aggregate the importance weights and rating of alternatives performance.

Decision makers use the linguistic terms in Table 1 and 2 to evaluate the importance of each criterion and the rating of each alternative against each criterion. The rating results are tabulated in Tables 3 and 4.

Table 3: Linguistic terms and its fuzzy numbers for the importance weigh of each criterion

Criterion	Decision makers		
	K1	*K2*	*K3*
C1	I	I	I
C2	I	I	VI
C3	1	VI	VI
C4	VI	I	I

Table 4: Rating by decision makers with respect to the criteria

Criteria	Maintenance policy	Decision makers		
		K1	*K2*	*K3*
C1	A1	VL	L	VL
	A2	H	H	VH
	A3	H	H	VH
	A4	M	L	H
C2	A1	VL	VL	VL
	A2	M	H	M
	A3	H	H	VH
	A4	VH	H	M
C3	A1	L	VL	VL
	A2	VH	VH	H
	A3	VH	VH	VH
	A4	M	H	L
C4	A1	H	H	H
	A2	VH	H	VH
	A3	M	L	M
	A4	M	H	H

The average rating aggregate from *K*s is computed using Equation (2) as follow.

Table 5: Average fuzzy weighting for each criterion

Criteria	Average weighting
C1	(0.250, 0.500, 0.750)
C2	(0.333, 0.583, 0.833)
C3	(0.417, 0.667, 0.917)
C4	(0.333, 0.583, 0.833)

Step 2: Formulation of fuzzy decision matrix

The graded mean integration of each maintenance policy against criterion performed according to Equation (1) is constructed into matrix form as shown in Table 6.

Table 6: Fuzzy decision matrix

Maintenance policy	Criteria			
	C1	C2	C3	C4
A1	(1.000, 1.6667, 3.67)	(1.000, 1.000, 3.000)	(1.000, 1.667, 3.667)	(5.000, 7.000, 9.000)
A2	(5.667, 7.667, 9.000)	(3.667, 5.667, 7.667)	(6.333, 8.333, 9.000)	(6.333, 8.333, 9.000)
A3	(5.667,7.667, 9.000)	(5.667, 7.667, 9.000)	(7.000, 9.000, 9.000)	(2.333, 4.333, 6.333)
A4	(3.000, 5.000, 7.000)	(5.000, 7.000, 8.333)	(3.000, 5.000, 7.000)	(4.333, 6.333, 8.333)

Step 3: Normalization of decision matrix is performed in this step by using Equation (4) and put into Table 7.

Table 7: Normalized decision matrix

Maintenance Policy	C1	C2	C3	C4
A1	(0.111, 0.218, 0.408)	(0.333, 1.000, 0.333)	(0.111, 0.186, 0.408)	(0.556, 0.778, 1.000)
A2	(0.630, 1.000, 1.000)	(0.272, 0.176, 0.130)	(0.703, 0.926, 1.000)	(0.703, 0.926, 1.000)
A3	(0.630, 1.000, 1.000)	(0.176, 0.130, 0.111)	(0.778, 1.000, 1.000)	(0.259, 0.481, 0.703)
A4	(0.333, 0.913, 0.778)	(0.200, 0.143, 0.120)	(0.333, 0.556, 0.778)	(0.481, 0.703, 0.926)

Step 4: Weighted of normalized fuzzy decision matrix.

The average fuzzy weighting tabulated in Table 5 are multiplied into normalized decision matrix using Equation (6), and formed into Equation (7). The weighted normalized fuzzy decision matrix is illustrated in Table 8.

Table 8: Weighted normalized fuzzy decision matrix

Maintenance policy	C1	C2	C3	C4
A1	(0.028, 0.109, 0.306)	(0.111, 0.583, 0.277)	(0.046, 0.124, 0.374)	(0.185, 0.454, 0.833)
A2	(0.158, 0.500, 0.750)	(0.091, 0.103, 0.108)	(0.293, 0.618, 0.917)	(0.234, 0.540, 0.833)
A3	(0.158, 0.500, 0.750)	(0.059, 0.076, 0.092)	(0.324, 0.667, 0.917)	(0.086, 0.280, 0.586)
A4	(0.083, 0.457, 0.584)	(0.067, 0.083, 0.099)	(0.139, 0.371, 0.713)	(0.160, 0.410, 0.771)

Step 5: Determine the FPIS and FNIS using Equation (8) and (9)

FPIS= [(1, 1, 1), (1, 1, 1), (1, 1, 1), (1, 1, 1), (1, 1, 1)]
FNIS= [(0, 0, 0), (0, 0, 0), (0, 0, 0), (0, 0, 0), (0, 0, 0)]

Step 6: Separation measurement

Distance of each maintenance alternatives from PIS and NIS is measured by using Equation (10) and (11). The results of calculation are presented in Table 9.

Table 9: Distance measurement

Maintenance policy	PIS	NIS
A1	2.969	1.353
A2	2.474	1.879
A3	2.657	1.664
A4	2.822	1.498

Step 7: Relative closeness measurement is performed according to Equation (12) and final ranking of the maintenance policies is revealed in Table 10.

Table 10: Ranking of the maintenance policy

Maintenance policy	Ranking
A1	0.838
A2	3.145
A3	1.674
A4	1.132

7. Discussion

The proposed method is applicable in selecting the optimal maintenance policy to improve the system availability by reducing its failure rates. The method consists of two stages and each stage has specific function that can enhance and give better result in the selection process. At the first stage, the fuzzy linguistic is adopted to overcome the problem of lacking of data or imprecision of data which is a problem faced by majority of company. Without a complete set of accurate data, the final result will not certainly accurate and may lead to worst condition. For instance, wrong policy lead to ineffective maintenance, furthermore, affect the productivity and company profit. Once a reliable data is gathered, an effective and straightforward method -- TOPSIS is utilized to analyze the collected information and determine the optimal maintenance policy.

The proposed method attends to maximize the utilities of the experts' experience from engineers and technicians. Knowledge from personnel's experience is intangible but valuable. They have first hand information and knowledge about the system. However, human judgment is always subjected to certain level of uncertainty due to different experience. Thus, fuzzy approach is adopted in order to capture information from these people with better accuracy. With this, the optimal maintenance policy can be identified according to the system's actual condition to further increase the system's performance.

Another merits on the method developed is the tendency to assist maintenance management to perform more effective analysis when data is not available or doubtful. By having an optimal maintenance policy, the company would have better utilization of their system and eventually complete and prompt deliveries of their project more successfully.

8. Conclusion

The fuzzy TOPSIS presented in this paper sets up some guidelines for maintenance management in evaluating and selecting the optimal maintenance policy. This method not only solves the vagueness inherent in the maintenance policy selection problem, but also increases the accuracy of the result by the implementation of fuzzy linguistic approach. With further research, this method can be implemented in industry to demonstrate its practicality in selecting the optimal maintenance policy.

References

1. Sharma, A., Yadava, G. S. and Deshmukh, S. G., 2011, "A literature review and future perspectives on maintenance optimization," Journal of Quality in Maintenance Engineering, 17(1), 5-25.
2. Gupta, S., Maiti, J., Kumar, R., and Kumar, U., 2009, "A control chart guided maintenance policy selection," International Journal of Mining, Reclamation and Environment, 23(3), 216-226
3. Labib, A. W., O'Connor, R. F., and Williams, G. B., 1998, "An effective maintenance system using the analytic hierarchy process," Integrated manufacturing Systems, 9(2), 87-98.
4. Mechefske, C. K., and Wang, Z., 2001, "Using fuzzy linguistics to select optimum maintenance and condition monitoring strategies," Mechanical Systems and Signal Processing, 15(6), 1129-1140.
5. Sharma, R. K., Kumar, D., and Kumar, P., 2005, "FLM to select suitable maintenance strategy in process industries using MISO model," Journal of Quality in Maintenance Engineering, 11(4), 359-374.
6. Tajiri, M., and Gotoh, F., 1992, TPM Implementation- A Japanese Approach, McGraw Hill Inc.
7. Wang, L., Chu, J., and Wu, J., 2007, "Selection of optimum maintenance strategies based on a fuzzy analytical hierarchy process," International Journal of Production Economics, 107(1), 151-163.
8. Schuh, G., Lorenz, B., Winter, C. P., and Gudergan, G., 2009, "The house of maintenance-identifying the potential for improvement in internal maintenance organization by means of a capability maturity model", Engineering Asset Management World Congress, Athens, Greece.

9. Zaied, R. A., and Abhary, K. 2009, “A design of an intelligent maintenance integrated system into manufacturing systems”, Industrial Technology, IEEE International Conference, Gippsland , VIC.
10. Bevilacqua, B., and Braglia, M., 2000, “The analytic process applied to maintenance strategy selection,” Reliability Engineering and System Safety, 70(1), 71-83.
11. Ratnayake, R. M. C., and Markeset, T., 2010, “Technical integrity management: measuring HSE awareness using AHP in selecting a maintenance strategy,” Journal of Quality in Maintenance Engineering, 16(1), 44-63.
12. Tan, Z., Li, J., Wu, Z., Zheng, J., and He, W., 2011, “An evaluation of maintenance strategy using risk based inspection,” Safety Science, 49(6), 852-860.
13. Al-Najjar, B., and Alsyouf, I., 2003, “Selecting the most efficient maintenance approach using fuzzy multiple criteria decision making,” International Journal of Production Economics, 84(1), 85-100.
14. Bertolini M., and Bevilacqua, M., 2006, “A combined goal programming-AHP approach to maintenance selection problem,” Reliability Engineering and System Safety, 91(7), 839-848.
15. Jafari, A., Jafarian, M., Zareei, A., and Zaerpour, F., 2008, “Using fuzzy Delphi method in maintenance strategy selection problem,” Journal of Uncertain Systems, 2(4), 289-298.
16. Shyjith, K., Ilangkumaran, M., and Kumanan, S., 2008, “Multi-criteria decision-making approach to evaluate optimum maintenance strategy in textile industry,” Journal of Quality in Maintenance Engineering, 14(4), 375-386.
17. Arunraj, N. S., and Maiti, J., 2010, “Risk-based maintenance policy selection using AHP and goal programming,” Safety Science, 48(2), 238-247.
18. Ilangkumaran M, Kumanan S. Selection of maintenance policy for textile industry using hybrid multi-criteria decision making approach. *Journal of Manufacturing Technology Management* 2009; **20**(7): 1009-1022.
19. Ghosh, D., and Roy, S., (2010), “A decision-making framework for process plant maintenance”, European Journal of Industrial Engineering, 4(1), 78-98.
20. Ahmadi, A., Gupta, S., Karim, R., and Kumar, U., (2010) “Selection of maintenance strategy for aircraft systems using multi-criteria decision making methodologies”, International Journal of Reliability, Quality and Safety Engineering, 17(3), 223-243.
21. Chen FL, and Chen YC. Evaluating the maintenance performance of the semiconductor factories based on the analytical hierarchy process and grey relational analysis. *American Journal of Applied Sciences* 2010; **7**(4): 567-574.
22. Mousavi SS, Nezami FG, Heydar M, Aryanejad MB. A hybrid fuzzy group decision making and factor analysis for selecting maintenance strategy. *Computers & Industrial Engineering International Conference Proceedings*, Troyes, 2009; 1204-1209.
23. Bashiri M, Badri H, Hejazi TH. Selecting optimum maintenance strategy by fuzzy interactive linear assignment method. *Applied Mathematical Modelling* 2011; 35(1): 152-164.
24. Pohekar, S. D., and Ramachandran, M., 2004, “Application of multi-criteria decision making to sustainable energy planning- a review,” Renewable and Sustainable Energy Reviews, 8(4), 365-381.
25. Chen, C. T. (2000), Extensions of the TOPSIS for group decision-making under fuzzy environment, Fuzzy Sets and Systems, 114, 1-9.