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A Combined Approach for Maintenance Strategy Selection

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Abstract: In this research, a methodology was proposed to select optimum maintenance strategy. The study suggested a methodology which applied various steps. This research considered developing a list of criteria with the recognition of patterns amongst those criteria. Having developed the hierarchy structure, then the paper illustrates the use of an AHP improved by Rough set to eliminate the inconsistency commonly existing in the AHP method. A case study is used to demonstrate the application of the various steps of the proposed methodology.

Key words: Maintenance strategies, analytical hierarchy process, rough set theory, factor analysis

INTRODUCTION

Nowadays with increasing Technology's development and develop Industry's automation and increase of machinery's quantity, volume of investment in organization's physical assets and machineries have increased significantly. One of the fundamental items for these factories is the cost of maintenance that can reach 15-70% of production costs based on type of industry (Bevilacqua and Braglia, 2000). The amount of money spent on maintenance in a selected group of companies is estimated to be about 600 billion dollars in 1989 (Chan and Law, 2005). Annual maintenance cost in comparison with turn over in some of European countries, based on survey results of European Federation of National Maintenance Societies (EFNMS) in 1990 is: Belgium 4.8, France 4, Ireland 5.1, Italy 5.1, Netherlands 5, Spain 3.6 and UK 3.7%. Furthermore, maintenance plays a key role in reliability capability, availability, products quality, risk reduction, increasing efficiency, equipment safety and etc. In this regard, maintenance and its strategies are of special importance in Industry. In this research, we will go through the five most important kinds of strategies put forward that include: corrective, preventative, opportunistic, condition-based and predictive maintenance.

Implementation costs both in terms of fixed investments and assignment of people are high; hence, we don't want to repeat it for some time. On the other hand, there exist multiple criteria and multiple perspectives that should be considered and taken heed of in this decision making. Decision making process and judgment regarding selection of maintenance strategy are often discontinuous, complex and unstructured (Hajshirmohammadi and Wedley, 2004) and it is necessary to be considered the great number of attributes and miscellaneous factors that some of them are intangible (Bevilacqua and Braglia, 2000).

To solve this kind of problems, some multiple criteria decision approaches have been suggested. In particular, Almeida and Bohoris (1995) considered the application of decision-making theory to maintenance paying special attention to the multiple attribute utility theory. Triantaphyllou *et al.* (1997) suggested the use of the analytical hierarchy process considering only four maintenance criteria: cost, repairability, reliability and availability. Azadivar and Shu (1999) presented the method to select a suitable maintenance strategy for each class of systems in a just-in-time environment, exploring 16 characteristic factors that could play a role in maintenance strategy selection. Bevilacqua and Braglia (2000) presented an application of the AHP technique for maintenance strategy selection in an Italian oil refinery processing plant, combining many features which are important in the selection of the maintenance policy: economic factors, applicability and costs, safety, etc. Al-Najjar and Alsyouf (2003) and Sharma *et al.* (2005) assessed the most popular maintenance strategies using the fuzzy inference theory and fuzzy multiple criteria decision making evaluation methodology. Okumura and Okino (2003) showed the methods to select the most effective maintenance strategy based on different production loss and maintenance costs incurred by different maintenance strategies. Mechefske and Wang (2003) proposed a model that evaluate and select the optimum maintenance strategy and condition monitoring

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technique making use of fuzzy linguistics. Hajshirmohammadi and Wedley (2004) proposed a systematic model for evaluating different maintenance organizational structures with respect to the objectives of a maintenance department. This model provided step by step guidelines for the maintenance management and decision makers to go through the evaluation process. Carnero (2005) proposed a model that carries out the decision making in relation to the selection of the diagnostic techniques and instrumentation in the predictive maintenance programs. Her model used a combination of tools belonging to operation research such as analytic hierarchy process and factor analysis. Bertolini and Bevilacqua (2006) presented a goal programming approach to define the best strategies for the maintenance of critical centrifugal pumps in an oil refinery. Wang (2007) proposed a model that helps management to select optimum maintenance strategies based on a fuzzy analysis hierarchy process.

In this research, we with the help of going over expertise of experts and their relevant specialized literature try to recognize variables and effective criteria in selecting maintenance strategy. Then, by using factor analysis, we will process the data so that we can designate fundamental variables and summarize them in some factors. Then after, we will apply the results from factors analysis for nomination of criteria in a hierarchy structure. Consequently, to choose best strategy, we will evaluate and determine weight of each maintenance strategy by improving AHP with rough set theory. By using rough set theory in AHP method the qualitative judgment can be qualified to make comparison more intuitionistic and reduce or eliminate assessment bias in pairwise comparison process.

MAINTENANCE STRATEGIES

In this research, we have gone through 5 types of maintenance strategies as fellows:

Corrective maintenance: This alternative maintenance strategy is also named as fire-fighting maintenance, failure based maintenance or breakdown maintenance. When the corrective maintenance strategy is applied, maintenance is not implemented until failure occurs (Swanson, 2001). Corrective maintenance is the original maintenance strategy appeared in industry (Chan and Lau, 2005; Wang, 2007). It is considered as a feasible strategy in the cases where profit margins are large (Sharma *et al*., 2005). However, such a fire-fighting mode of maintenance often causes serious damage of related facilities, personnel and environment. Furthermore, increasing global competition and small profit margins have forced maintenance managers to apply more effective and reliable maintenance strategies.

Preventative maintenance: This approach is based on component reliability characteristics. This data makes it possible to analyze the behavior of the element in question and allows the maintenance engineer to define a periodic maintenance program for the machine. The preventive maintenance policy tries to determine a series of checks, replacements and/or component revisions with a frequency related to the failure rate. In other words, preventive (periodic) maintenance is effective in overcoming the problems associated with the wearing of components. It is evident that, after a check, it is not always necessary to substitute the component: maintenance is often sufficient. For performing preventive maintenance, a decision support system is needed and it is often difficult to define the most effective maintenance intervals because of lacking sufficient historical data (Mann *et al*., 1995). In many cases when maintenance strategies are used, most machines are maintained with a significant amount of useful life remaining (Mechefske and Wang, 2003). This often leads to unnecessary maintenance, even deterioration of machines if incorrect maintenance is implemented.

Opportunistic maintenance: The possibility of using opportunistic maintenance is determined by the nearness or concurrence of control or substitution times for different components on the same machine or plant. This type of maintenance can lead to the whole plant being shut down at set times to perform all relevant maintenance interventions at the same time. Therefore, this maintenance strategy requires coordination and support from production's personnel.

Condition-based maintenance: Maintenance decision is made depending on the measured data from a set of sensors system when using the condition-based maintenance strategy. To date a number of monitoring techniques are already available, such as vibration monitoring, lubricating analysis and ultrasonic testing. The monitored data of equipment parameters could tell engineers whether the situation is normal, allowing the maintenance staff to implement necessary maintenance before failure occurs. This maintenance strategy is often designed for rotating and reciprocating machines, e.g. turbines, centrifugal pumps and compressors. But limitations and deficiency in data coverage and quality reduce the effectiveness and accuracy of the condition-based maintenance strategy (Alnajjar and Alsyouf, 2003).

Predictive maintenance: Unlike the condition-based maintenance policy, in predictive maintenance the acquired controlled parameters data are analyzed to find a possible temporal trend. This makes it possible to predict when the controlled quantity value will reach or exceed the threshold values. The maintenance staff will then be able to plan when, depending on the operating conditions, the component substitution or revision is really unavoidable.

MAINTENANCE STRATEGY SELECTION CRITERIA

Selection of maintenance strategy in each organization depends on many criteria. This decision especially effects on how to allocate resource, technology selection, management and organization process, etc. Hence, to select suitable strategy, it is necessary to choose this decision commensurate with fact. Studying related articles to maintenance strategies (Alnajjar and Alsyouf, 2003; Bevilacqua and Braglia, 2000; Triantaphyllou *et al*., 1997; Wang, 2007) and also using expertise, we have recognized key and crucial criteria for selection of maintenance strategy; recognized criteria are as follow:

Services quality	Risk
Equipment's wear and tear	Personnel training
Product's defect	Environmental effects
Equipment's set up time	Personnel wage
Customer satisfaction	Equipments and personnel efficiency
Personnel damages	Product's quality
Software cost	Reliability
Hardware facilities	Hardware cost
Software facilities	Equipment safety
Skillful human resources	

In order to take a suitable and accurate decision that satisfies organization's requirements, paying attention to above mentioned criteria is crucial and vital.

MATERIALS AND METHODS

Proposed methodology comprises 5 steps. Generally this methodology after recognizing important criteria with the help of one of multivariate analysis techniques have formed the decision tree and with the application of AHP has improved by rough set theory has assessed each maintenance strategy. These steps have been detailed as it continues.

Step 1: We with the help of going over expertise of experts and their relevant specialized literature try to recognize 19 variables and effective Criteria in maintenance strategy selection

Step 2: Since considering all criteria for maintenance strategy selection seems to be impossible it seems to be necessary to use a dimension decreasing technique for extracting pattern and summing up criteria. In this methodology due to considering mutual relation between factors for decreasing dimensions and recognition of patterns, factor analysis has been used as one of the most applicable and suitable techniques of multivariate analysis

Step 3: With regard to the essence of each group criteria placed in each factor, we have labeled recognition factors in preceding stage. Then hierarchical tree is formed

Step 4: With the improvement of AHP technique, by rough set theory it would become possible to reach to consistent comparison. By using rough set theory in AHP method the qualitative judgment can be qualified to make comparison more intuitionistic and reduce or eliminate assessment bias in pair wise comparison process

Step 5: In order to calculate the final score of each supplier, the weight of criteria, sub criteria and maintenance strategy's information should be combined.

A short description of using techniques

Factor analysis (FA): Factor analysis is a general term that is given to a group of statistical multivariate methods which their primary goal is to define covert structure in data. In general terms by defining a collection of joint covert dimensions that are referred to as factors, it analysis relations structure (correlation) amongst great volume of variables (Thompson, 2004). The aim of FA techniques is to find the synopsis of available data in initial quantity of variables and conversion of them to a smaller collection of dimensions or new combination factors with less data missing (Lattin *et al*., 2003).

Improved AHP using rough set theory: AHP is a well known technique to help the analysts to organize the critical aspects of a problem into a hierarchical structure for making a decision (Saaty, 1980). In this technique, the Consistency Index (CI) is used as a measure of consistency of the judgments, where CI = (λ_{max}-n)/ (n-1), where λ_{max}, is the biggest eigenvalue and n is dimension of the matrix. In AHP, the pairwise comparisons in a judgment matrix are considered to be adequately consistent if the corresponding Consistency Ratio (CR) is less than 10%. If the CR value is greater than 0.10, then a re-evaluation of the pairwise comparisons is recommended (Saaty, 1980).

Rough set theory, proposed by Pawlak (1982), is a new mathematical approach to data analysis. The basic idea behind this method is the classification of objects into similar classes (clusters) to find hidden patterns in the data (Nelson and Starzyk, 2001).

For the propose of reducing subjective extent of human judgment, we propose decision table approach for obtaining more objective weights. Conditional entropy and attribute significance concepts in rough sets theory can be used in AHP to improve the judgment consistency (Xia and Wu, 2007). We consider the use of the concept of attribute significance in rough sets theory proposed by Wang (2001) to eliminate evaluation bias problem in AHP. Some important concepts used in the proposed methodology are discussed below (Xia and Wu, 2007).

Formally, a data table is the 4-tuple S = {U,R,V,f}, where U is a finite set of objects (universe); R = C∪D is a set of attributes, subsets C and D are the condition attribute set and the decision attribute set, respectively; V_r is the domain of the attribute r, $V = \cup_{r\in R} V_r$ and f: U×R→V is a total function such that f (x,r)∈V_r for each r∈R, x∈U, called information function. To every non-empty subset B of attributes R (B⊆R) is associated an indiscernibility relation on U, denoted by IND (B):

$$\text{IND (B)} = \{(x, y) \mid (x, y)\in U\times U, \forall b\in B, (b(x) = b(y))\}$$

Clearly, the indiscernibility relation defined is an equivalence relation (reflexive, symmetric and transitive). The family of all the equivalence classes of the relation IND (B) is denoted by U|IND (B).

Definition 1: Entropy H (P) of knowledge P (attributes set) is defined as

$$H(P) = -\sum_{i=1}^{n} p(X_i)\log_2^{P(X_i)}$$

where, p (X_i) = |X_i|/|U| and p (X_i) denotes the probability of X_i when P is on the partition

$$X = \{X_1, X_2, ..., X_n\} \text{ of universe U, } i = 1, 2, ..., n.$$

Definition 2: Conditional entropy H (Q|P) which knowledge Q (U|IND (Q) = {Y_1, Y_2, ..., Y_m}) is relative to knowledge P (U|IND (P) = {X_1, X_2, ..., X_n}) is defined as:

$$H(Q|P) = -\sum_{i=1}^{n} P(X_i)\sum_{j=1}^{m} P(Y_j|X_i)\log_2^{P(Y_j|X_i)}$$

where, p (Y_j|X_i) is conditional probability, i = 1, 2, ..., n, j = 1, 2, ..., m.

Definition 3: Suppose that decision table S = {U, R, V, f}, R = C ∪ D, subsets C and D are the condition attribute set and the decision attribute set, respectively, attribute subset A ⊂ C. The attribute significance SGF (a, A, D) of attribute a (a∈C\A) is defined as SGF (a, A, D) = H (D|A)-H (D|A∪{a}). Given attribute subset A, the greater the value of SGF (a, A, D), the more important attribute a is for decision D.

Application of factor analysis to identify key criteria in maintenance strategy selection: Here, we have introduced key criteria for decision making regarding selection of maintenance strategies. Taking into account all 19 criteria for decision making is a complicated and high error probable process. For the application of factor analysis we need data commensurate with facts that clarify the relation between criteria. For this reason a questionnaire was prepared and 96 experts in this field were queried so that required data was obtained.

After application of FA technique on data, following results were shown in Table 1; elements of the factor loading matrix pertinent to criteria for 4 factors after rotation (based on varimax method) have shown. In this methodology for extracting factors, method of eigenvalue bigger than 1 has been used.

Table 1: Results of FA after rotation

Rotate (criteria)	Factor 1	Factor 2	Factor 3	Factor 4
Services quality	-0.0920	0.6855	0.0161	-0.0830
Equipment's ware and tear	0.6254	0.0770	0.4240	0.1703
Personnel training	0.6594	0.2098	0.0786	0.1930
Software cost	0.8315	-0.1760	0.0517	0.0558
Hardware facilities	-0.0250	0.0340	0.8502	0.0102
Product's defect	0.0330	0.0143	0.0942	-0.4800
Software facilities	0.0686	-0.2800	0.4149	-0.2280
Equipment's set up timing	0.8287	-0.2870	0.0519	0.0460
Skillful human resources	0.0616	-0.0550	0.7612	0.0899
Customer satisfaction	-0.1140	0.6267	-0.0070	0.1203
Equipment safety	-0.1460	-0.0620	0.0680	-0.6560
Personnel damages	0.0734	0.1458	0.3732	0.4362
Hardware cost	0.6132	-0.0990	-0.0270	0.0889
Product's quality	-0.1840	0.8166	-0.0520	0.1651
Environmental effects	0.3764	0.1874	-0.2669	0.4429
Equipment and Personnel efficiency	-0.2360	0.3737	0.0262	-0.1250
Personal wage	0.6466	-0.2440	0.2048	0.1704
Risk	0.2444	0.2335	0.3368	0.6019
Reliability	-0.1640	0.0668	-0.2250	-0.5040

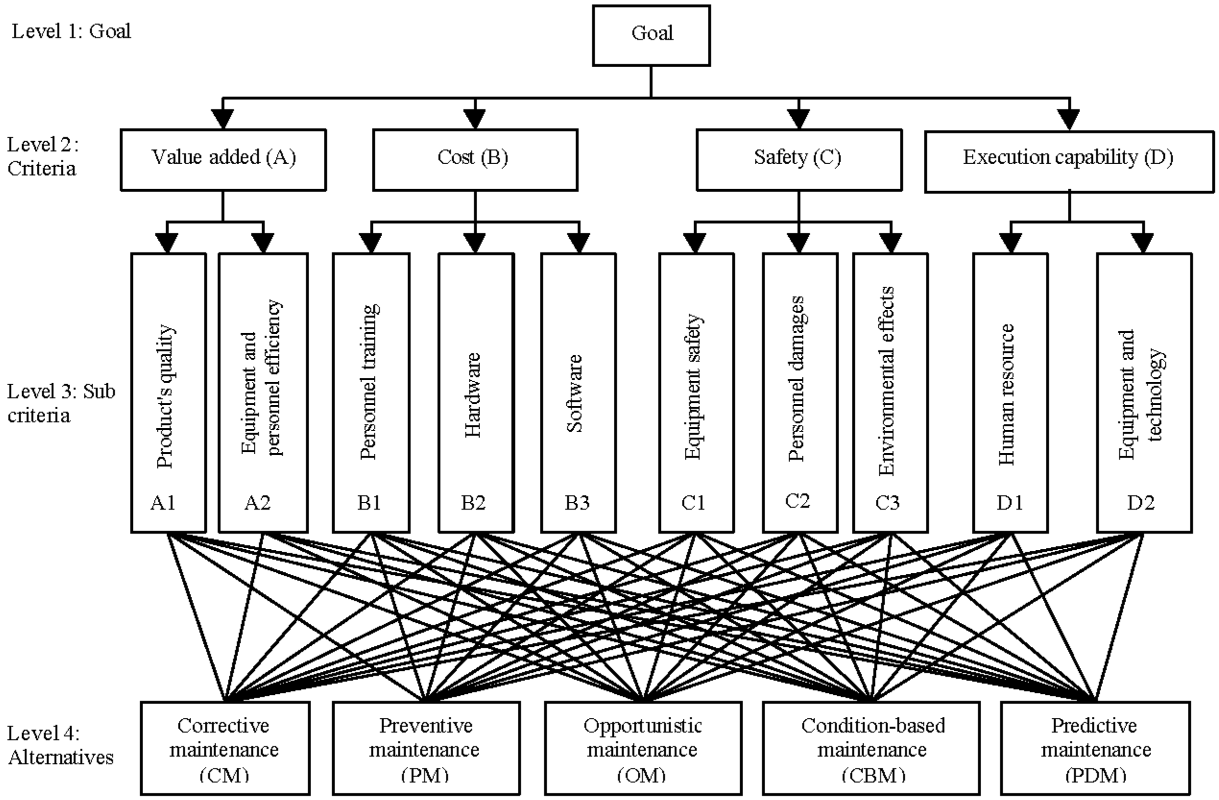

Fig. 1: Decision tree and selection of maintenance strategy

After factor rotation, allocation of criterion to factor is executed with higher accuracy and less error. For example, services quality criterion will be obviously allocated to factor 2.

Selection of these 4 factors has the capability of deducing 78.8% of data. Now, we make a distinction of allocated criteria in each factor. Obtain result have been shown in Table 2. This makes it easier to label factors.

Equipment tear and ware criterion, education of personnel, software cost, installation and set up timing of equipment, Hardware cost and personnel wages, all have been allocated to factor 1. Investigating these criteria, it is understood that all of them are cost and refer to cost calculation; therefore, we have named factor 1 as cost. We further label other 3 factors, which its results culminates in naming factor 2 as value added, factor 3 as execution capability and finally factor 4 as safety.

Making hierarchy tree: We proposed results obtained from factor analysis and connection between factors and criteria to a maintenance assessment team that includes experts in this field. After defining a general goal that was selection of maintenance strategy, we tried to visualize a hierarchical structure that included criteria, sub criteria

Table 2: Allocation criteria to suitable factor

Criteria	Factor 1	Factor 2	Factor 3	Factor 4
Equipment's ware and tear	0.6254			
Personal training	0.6254			
Software cost	0.8315			
Equipment's set up timing	0.8287			
Hardware cost	0.6132			
Personal wage	0.6466			
Services quality		0.6855		
Customer satisfaction		0.6267		
Product's quality		0.8166		
Equipment and personnel Efficiency		0.3737		
Hardware facilities			0.8502	
Software facilities			0.4149	
Skillful human resources			0.7612	
Product's defect				-0.480
Equipment safety				-0.656
Personnel damages				0.4362
Environmental effects				0.4429
Risk				-0.504
Reliability				-0.504

and choices related to acquiring the general goal that its results have been shown in Fig. 1.

Goal is selecting the best maintenance strategy that includes 4 criteria; value added (A), Cost (B), safety (C) and execution capability (D). Value added criterion includes 2 sub criteria of products quality (A1) and equipment and personnel efficiency (A2). Criterion of cost constitutes 3 sub criteria of personnel training cost (B1), hardware costs (B2) and software costs (B3). Criterion of safety constitutes 3 sub-criteria of equipment safety (C1), personnel damages (C2) and environmental effects (C3). Criterion of execution capability includes 2 sub-criteria of Human resource (D1) and equipment and technology (D2). Five options of corrective maintenance (CM), preventative maintenance (PM), opportunistic maintenance (OM), condition-based maintenance (CBM) and predictive maintenance (PdM) have been considered for selection. This hierarchical structure can tremendously help in suitable and accurate decision making for selection of maintenance strategy in organizations.

CASE STUDY

Here, an industrial unit for the selection of best maintenance strategy with regard to stated methodology earlier has been studied. This industrial unit is active in producing standard parts. Most of produced productions in this complex constitute products such as screw basic and spring nut, gasket, different kinds of metal spangles (disks) and hinges in miscellaneous sizes. In the process of production of these productions, different equipments such as lathes, die and press, CNC, welding and are used. For the time being, maintenance strategy of this unit is corrective one and activity of maintenance unit is taken place only after equipments break down. In the past, due to high profit margin and exclusivity in the market, this strategy was applied by the management.

But currently considering the huge volume of production and necessity for diminution of stopping production line and converting the market to a competitive market, necessity for altering the maintenance strategy seems to be a vital issue. Because, an appropriate maintenance strategy results in reduction of over head costs, preserving reliability level, increase of product's quality and customer satisfaction.

Management is willing to decide new maintenance strategy without huge amount of investment. With regard to methodology of mentioned earlier, goal is choosing the best strategy from amongst 5 strategies mentioned. Considering that steps 1, 2 and 3 have been applied in prior selections, in this part we only deal with application of steps 4, 5. In step 4, for assessment of criteria with the help of improved AHP by rough set theory, the procedure is as follows: initially for each of mentioned criterion in Fig. 1, a value such as the values of 1, 2 and 3 which are associated with low, middle, high or good, middle, poor is selected. These numerical quantities of scale are chosen in consideration of essence of criteria. In Table 3, these quantities have been mentioned for different criteria.

In next stage in order to evaluate criteria, a list of their different combinations is made. We should pay attention that necessarily all possible combinations are not considered in this list. Different combinations are definable based on approach and view point of management of each organization. For example this list mentions Value added (A), cost (B), safety (C) and execution capability (D) criteria in Table 4.

Table 3: Identification of scale for the criteria

No.	Criteria	Scale*	No.	Criteria	Scale*
1	A	Z	8	B2	Y
2	B	Y	9	B3	Y
3	C	X	10	C1	X
4	D	X	11	C2	Y
5	A1	X	12	C3	Y
6	A2	Z	13	D1	Z
7	B1	Y	14	D2	X
*	1	2	3		
X	High	Middle	Low		
Z	Good	Middle	Poor		
Y	Low	Middle	high		

Value of 1 in decision column for each row mentions selection of that row's conditions and value of zero shows nonacceptance of that row's conditions by the decision maker. For example, row 17 shows that if value added, cost, safety and execution capability are good, middle, high and middle, respectively, decision maker doesn't have any willingness for realization of these conditions and values it as zero. For finding mentioned criteria weight in Table 4. In accordance with following process, it is done based on rough set theory.

U | IND{A, B, C, D} = {{1}, {2}, {3}, {4}, {5}, .., {43}, {44}}

U | IND{d} = {{7, 8, 15, 16, 26, 27, 28, 30, 31, 32, 33, 34, 36, 40, 41, 43, 44}, {1, 2, 3, 4, 5, 6, 9, 10, 11, 12, 13, 14, 17, 18, 19, 20, 21, 22, 23, 24, 25, 29, 35, 37, 38, 39, 42}} = {Y_1, Y_2}

U | IND{ B, C, D} = {{1, 21, 38}, {2, 22, 39}, {3, 23}, {4, 24, 40}, {5, 25, 41}, {6, 26}, {7, 27}, {8, 28}, {9, 29, 42}, {10, 30, 43}, {11, 31}, {12, 32, 44}, {13, 33}, {14}, {15, 34}, {16}, {17, 35}, {18, 36}, {19, 37}, {20}} = {X_1, X_2, X_3, X_4, X_5, ..., X_{19}, X_{20}}

U | IND{A, C, D} = {{1, 9, 17}, {2, 10, 18}, {3, 11}, {4, 12, 19}, {5, 13, 20}, {6, 14}, {7, 15}, {8, 16}, {21, 29, 35}, {22, 30, 36}, {23, 31}, {24, 32, 37}, {25, 33}, {26}, {27, 34}, {28}, {38, 42}, {39, 43}, {40, 44}, {41}} = {K_1, K_2, K_3, K_4, K_5, ..., K_{19}, K_{20}}

U | IND{A, B, D} = {{1, 4, 7}, {2, 5, 8}, {3, 6}, {9, 12, 15}, {10, 13, 16}, {11, 14}, {17, 19}, {18, 20}, {21, 24, 27}, {22, 25, 28}, {23, 26}, {29, 32, 34}, {30, 33}, {31}, {35, 37}, {36}, {38, 40}, {39, 41}, {42, 44}, {43}} = {L_1, L_2, L_3, L_4, L_5, ..., L_{19}, L_{20}}

U | IND{A, B, C} = {{1, 2, 3}, {4, 5, 6}, {7, 8}, {9, 10, 11}, {12, 13, 14}, {15, 16}, {17, 18}, {19, 20}, {21, 22, 23}, {24, 25, 26}, {27, 28}, {29, 30, 31}, {32, 33}, {34}, {35, 36}, {37}, {38, 39}, {40, 41}, {42, 43}, {44}} = {V_1, V_2, V_3, V_4, V_5, ..., V_{19}, V_{20}}

Table 4: Decision table about value added (A), cost (B), safety (C) and execution capability (D)

No.	A	B	C	D	Decision
1	2	1	1	3	1
2	2	1	2	1	1
3	1	1	2	2	1
4	1	3	2	1	1
5	2	2	2	1	0
6	2	2	2	2	0
7	1	1	3	1	0
8	1	1	3	2	0
9	3	2	2	1	0
10	2	1	3	1	0
11	2	1	3	2	0
12	2	2	1	2	0
13	1	3	1	2	1
14	1	1	2	3	1
15	1	2	2	2	1
16	1	2	3	1	0
17	1	2	3	2	0
18	3	1	1	2	1
19	1	3	1	1	1
20	2	1	1	2	1
21	1	2	1	2	1
22	2	2	1	3	0
23	3	2	1	2	0
24	1	2	2	1	1
25	2	2	1	1	1
26	1	2	2	3	1
27	1	1	1	1	1
28	1	2	1	3	1
29	2	2	3	1	0
30	3	2	1	1	1
31	1	1	2	1	1
32	2	3	1	1	1
33	1	2	1	1	1
34	2	1	2	2	1
35	2	1	2	3	0
36	3	1	2	2	0
37	2	1	1	1	1
38	2	3	1	2	0
39	3	1	2	1	0
40	2	3	2	1	1
41	3	1	1	1	1
42	1	3	2	2	1
43	1	1	1	2	1
44	1	1	1	3	1

After definition of above set probabilities $P(X_i)$, $P(Y_j|X_i)$ are calculated that results have been Shown in Table 5.

As it is shown in Table 6, importance of A, B, C and D criteria are 0. 1396, 0.0805, 0.2003 and 0.0698 respectively.

If superiority of importance of choices i and j are respectively as W_i and W_j, pairwise comparison matrix for these 4 criteria is formed as below:

$$\begin{bmatrix} \frac{W_A}{W_A} & \frac{W_A}{W_B} & \frac{W_A}{W_C} & \frac{W_A}{W_D} \\ \frac{W_B}{W_A} & \frac{W_B}{W_B} & \frac{W_B}{W_C} & \frac{W_B}{W_D} \\ \frac{W_C}{W_A} & \frac{W_C}{W_B} & \frac{W_C}{W_C} & \frac{W_C}{W_D} \\ \frac{W_D}{W_A} & \frac{W_D}{W_B} & \frac{W_D}{W_C} & \frac{W_D}{W_D} \end{bmatrix} = \begin{bmatrix} 1 & 1.733 & 0.687 & 1.999 \\ 0.577 & 1 & 0.397 & 1.154 \\ 1.456 & 2.522 & 1 & 2.910 \\ 0.500 & 0.867 & 0.344 & 1 \end{bmatrix}$$

Table 5: Probability values

I	$P(X_i)$	$P(Y_1|X_i)$	$P(Y_2|X_i)$
1	3/44	0	1
2	3/44	0	1
3	2/44	0	1
4	3/44	1/3	2/3
5	3/44	1/3	2/3
6	2/44	1/2	½
7	2/44	1	0
8	2/44	1	0
9	3/44	0	1
10	3/44	2/3	1/3
11	2/44	1/2	1/2
12	3/44	2/3	1/3
13	2/44	1/2	1/2
14	1/44	0	1
15	2/44	1	0
16	1/44	1	0
17	2/44	0	1
18	2/44	1/2	1/2
19	2/44	0	1
20	1/44	0	1

Table 6: Calculate the attribute significance

SGF (A, {B, C, D}, {d}) =	-2/44 (1/2 Log 1/2+1/2 Log 1/2)* 4 -3/44 (2/3 Log 2/3+1/3 Log 1/3)* 4 = 0.1396
SGF (B, {A, C, D}, {d}) =	-3/44 (1/3 Log 1/3+2/3 Log 2/3)* 2 -2/44 (1/2 Log 1/2+1/2 Log 1/2)* 3 = 0.0805
SGF (C, {A, B, D}, {d}) =	-2/44 (1/2 Log 1/2+1/2 Log 1/2) *4 -3/44 (2/3 Log 2/3+1/3 Log 1/3) *7 = 0.2003
SGF (D, {A, B, C}, {d}) =	-3/44 (1/3 Log 1/3+2/3 Log 2/3) *2 -2/44 (1/2 Log 1/2+1/2 Log 1/2) *2 = 0.0698

Table 7: Result of local and global weight

Main criteria	Local weight	Criteria	Local weight	Global weight
A	0.283	A1	0.583	0.165
		A2	0.118	0.417
B	0.163	B1	0.223	0.036
		B2	0.285	0.046
		B3	0.492	0.080
C	0.412	C1	0.215	0.089
		C2	0.658	0.271
		C3	0.127	0.052
D	0.142	D1	0.168	0.024
		D2	0.832	0.118

With the help of eigenvector method, weight of each criterion is calculated based on above matrix. These weights are 0.283, 0.163, 0.412 and 0.142 for A, B, C and D criteria respectively. As it was mentioned earlier improved AHP's specifications with the help of rough set theory, doing pairwise comparisons are completely consistent. In order to better understand this subject, calculation of afore mentioned consistency index matrix is done, in this matrix λ_{max} equals 4 and considering that $CI = \frac{\lambda_{max} - n}{n-1}$ and n = 4, CI quantity would be zero. This shows this idea that pairwise comparison matrix made by rough set theory is completely consistent. Similarly weights of all criteria and sub-criteria have been calculated and its results have been shown in Table 7.

Information of each of Maintenance strategy has been shown in Table 8.

Table 8: Maintenance strategy's information

Strategy	CM	PM	OM	CBM
A1 (Rate)	87	90	88	94
A2 (%)	86	90	91	96
B1 ($)	240	240	440	420
B2 ($)	9000	9800	12000	12000
B3 ($)	900	1050	1200	1200
C1 (Grade)	3	2	2	1
C2 (Rate)	0.06	0.05	0.02	0.02
C3 (Grade)	3	3	2	2
D1 (Grade)	1	1	2	2
D2 (Grade)	1	1	1	2

Table 9: Maintenance strategy's final weight

Strategy	CM	PM	OM	CBM
A1 (Rate)	0.032	0.033	0.032	0.034
A2 (%)	0.022	0.023	0.023	0.025
B1 ($)	0.010	0.010	0.005	0.006
B2 ($)	0.011	0.010	0.008	0.008
B3 ($)	0.020	0.017	0.015	0.015
C1 (Grade)	0.009	0.013	0.013	0.027
C2 (Rate)	0.019	0.023	0.057	0.057
C3 (Grade)	0.007	0.007	0.010	0.010
D1 (Grade)	0.007	0.007	0.004	0.004
D2 (Grade)	0.031	0.031	0.031	0.015
Final weight	0.1666	0.1733	0.1984	0.2001

After normalizing information and considering global weight in them, final weight of each supplier is calculated. Obtained results from final weight of each supplier have been shown in Table 9.

Amongst these 5 strategies, predictive maintenance strategy has the most weight and corrective maintenance strategy has the least weight. As a result, predictive maintenance strategy is selected as the best strategy for this technical unit.

CONCLUSION

In this study, one method has been provided for deciding best maintenance strategy. Five kinds of most important mentioned strategies that include corrective, preventative, opportunistic, condition based and predictive have been considered in this methodology. One optimal maintenance strategy could result in reduction of unnecessary maintenance costs and promotion of reliability and availability of equipments. Evaluation of these strategies is a decision making problem in multiple condition and numerous factors are effective in decision making.

In this methodology by utilizing the combination of two techniques of factor analysis and improved analytical hierarchy process by rough set theory, firstly we try to recognize key factors from amongst effective factors and then making a hierarchy structure and evaluation of strategies. Various steps of the methodology have been demonstrated using sample examples. These examples indicate industry specific use of the methodology as well as its being simple in application. One other important feature of the method as discussed in this paper is its capability to eliminate inconsistency in AHP application. In a case study it has been mentioned that this methodology can help us effectively for selecting optimal strategy.

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