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MAINTENANCE STRATEGY EVALUATION BASED ON AHP – TOPSIS

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ABSTRACT

This paper presents an application of Analytical Hierarchy Process (AHP) is combined with Technique for Order Preference by Similarly to Ideal Solution (TOPSIS) model for selection of the best maintenance strategy for pump in paper industry. AHP is used to compute the criteria weights whereas TOPSIS is used to ranking the maintenance strategy alternatives. This study focuses on four maintenance strategies such as Corrective Maintenance (CM), Predictive maintenance (PM), Time based preventive Maintenance (TM) & Condition Based Maintenance (CBM) and four main criteria such as safety, cost, added value and feasibility are used to evaluate the optimum maintenance strategy.

Keywords

Analytical Hierarchy Process (AHP), Technique for Order Preference by Similarly to Ideal Solution (TOPSIS) and Maintenance strategies.

INTRODUCTION

Maintenance system plays a vital role in the development and progress of manufacturing and process industries. In general, operation and maintenance are synonymous with high level of availability, reliability and assets' operability linking with production and profit of the organization. Improper maintenance of the equipment leads to increase the production cost of the manufacturing goods. Bevilacqua and Braglia (2000) stated that the renovation price various from 15-70% of general manufacturing price according to the sort of the enterprise due to loss of upkeep. Maintenance options vary depending on the equipment and its location. In order to reduce the failures of the equipment, the different maintenance strategies are considered. The evaluation and selection of suitable maintenance strategy involves various conflicting criteria. To handle this problem various MCDM models are developed and proposed by the researchers over the past few decades. This paper describes an application of hybrid MCDM model for the selection of suitable maintenance strategy for critical equipment pump in paper industry. The paper is organized as follows: Literature on maintenance strategy selection using MCDM technique is summarized in section 2. The proposed MCDM techniques are detailed in section 3. Evaluation frame work of maintenance strategy selection and numerical application of the proposed model are explained and illustrated in sections 4 and 5. The obtained results are discussed in section 6. The final section concludes with future research direction.

2. RELATED WORK

The industries are geared up with all sorts of modest and sophisticated machineries which require a notable deal of maintenance strategies. de Almeida and Bohoris (1995) suggested a maintenance decision making model based on decision theory. Sachdeva et al. (2008) has made an attempt to minimize the cost of maintenance by considering the availability, maintenance cost and life cost. Wang et al. (2007) reported that maintenance strategy selection involves various evaluation criteria such as safety, cost, added value and feasibility. Ilangkumaran and kumanan (2009) reported that evaluation of maintenance strategy selection is approximated with few factors makes the decision unrealistic. Sadeghi and Manesh (2012) stated that number of conflicting criteria and constrains are considered for evaluating maintenance alternatives. Therefore MCDM methodology used for the maintenance strategy selection (Bashiri et al. 2011). Triantaphyllou et al. (1994) stated that Analytical Hierarchy Process (AHP) is the most popular tool among all other MCDM tools. Saaty and Vargas (1998) stated that the AHP derives the weights for criteria with the help of a pairwise comparison matrix where all identified criteria are compared against each other with a scale of relative importance. Nordgard et al. (2003) proposed a maintenance strategy selection model based on AHP for hydro power plant. Bevilacqua and Braglia (2000) described a maintenance strategy selection procedure to help of AHP for an Italian oil refinery. Even though the AHP is applied in the wider fiel, some authors have mentioned the issue of AHP. In AHP, the deterministic scale may produce some deceptive consequences and ranking of AHP is not always particular enough (Deng, 1999; Cheng et al. 1999; Mikhailov, 2003; Chan, 2003). Each and every MCDM technique has its own strengths and weakness and the performance can still be improved by combining two (or) more models. In this paper utilizes the MCDM methods to obtain the relative weight of each criteria through the AHP, whereas TOPSIS is used to obtain the final ranking of maintenance alternatives. The proposed models are demonstrated with the use of case studies from the paper industry.

3. METHODS

3.1 AHP Method

A complex decision-making problem is structured using hierarchy. The AHP initially breakdown a complex MCDM problem into a hierarchy of inter-related decision elements (criteria). In AHP, the criteria are organized in a hierarchical arrangement. A hierarchy has at least three levels: overall objective of the problem at the topmost, criteria at the central, and decision criteria at the lowest.

3.1.1 Procedural steps involved in AHP method are listed below:

The proposed framework of AHP model for maintenance strategy selection is shown in (Fig. 1). The model consists of three stages namely, (i) Goal, (ii) Evaluation criteria and sub criteria (iii) Maintenance strategy alternatives.

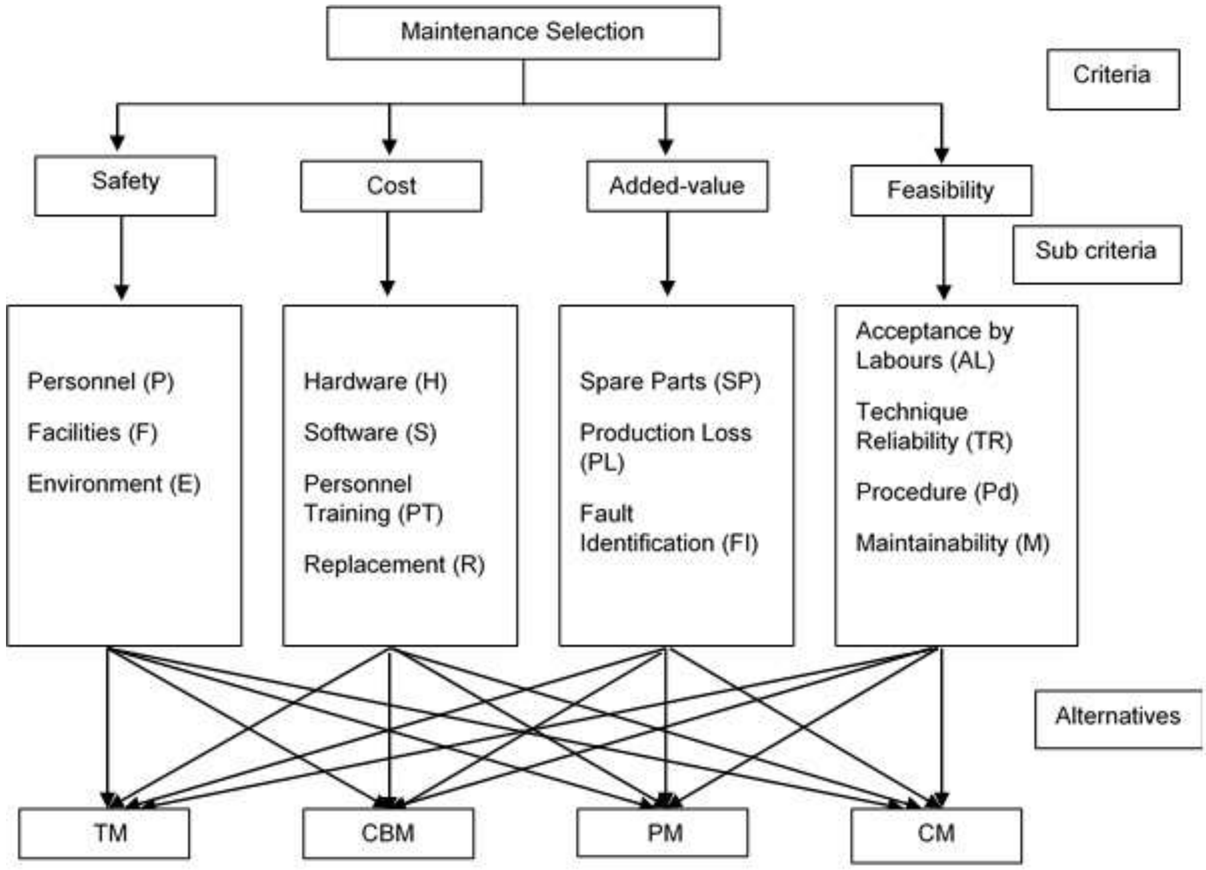

Fig 1: AHP model for maintenance strategy selection

The application of the AHP to the complex problem usually involves four major steps (Satty, T. L. (1980).

(a) Break down the complex problem into a number of small constituent elements and then structure the elements in a hierarchical form.

(b) Make a series of pairwise comparisons between the elements according to a ratio scale.

(c) Use the eigenvalue method to estimate the relative weights of the elements.

(d) Aggregate the relative weights and synthesis them for the final measurement of given decision alternatives. The procedure is detailed in fig. 2

Step 1: Construction of evaluation matrix

Let $C = \{C_j | j = 1,2,\dots\dots,n\}$ be a set of criteria. The result of pair wise comparison on 'n' criteria can be summarized in an (n × n) evaluation matrix A in which every element $a_{ij}(i,j = 1,2\dots\dots,n)$ is the quotient of the weights of the criteria, as shown:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \qquad a_{ii} = 1,\ a_{ij} = 1/a_{ji},\ a_{ij} \neq 0. \qquad (1)$$

Step 2: Calculation of relative weights

The mathematical process is commenced to normalize and find the relative weights of each matrix. The relative weights are given by the right Eigen vector (w) corresponding to the largest Eigen value (λ), as

$$A_w = \lambda_{max}\, w \qquad (2)$$

Step 3: Calculation of Consistency Index (CI)

It should be noted that the quality of output of AHP is strictly related to the consistency of the pair-wise comparison judgments. The consistency is defined by the relation between the entries of A: $a_{ij} \times a_{jk} = a_{ik}$. The Consistency Index (CI) is

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad (3)$$

Step 4: Calculation of consistency ratio (CR) value.

The consistency of the input in the pair wise matrix can be determined by calculating a consistency ratio (CR). In general, a CR having the value less than 0.1 is good Saaty (1980). The CR for each square matrix is obtained from dividing CI values by random consistency index (RCI) values.

$$CR = \frac{CI}{RCI} \qquad (4)$$

Step 5: Computation of desirability index

The desirability index has been calculated using the following equation:

$$D_i = \sum_{j=1}^{J} \sum_{k=1}^{KJ} P_j A_{kj}^{D} S_{ikj} \qquad (5)$$

Fig 2: Stepwise procedure of AHP

Where P_j is relative importance weight of criteria j; A_{kj}^{D} relative importance weight for sub-criteria k of j for the dependency; S_{1kj} relative impact of strategy alternative1 on sub-criteria k of criteria j of maintenance strategy selection hierarchy; S_{2kj} relative impact of strategy alternative 2 on sub-criteria k of criteria j of maintenance strategy selection hierarchy; S_{3kj} is the relative impact of strategy alternative 3 on sub-criteria k of criteria j of maintenance strategy selection hierarchy and S_{4kj} is the relative impact of strategy alternative 4 on sub-criteria k of criteria j of maintenance strategy selection hierarchy.

Table 1. Average RCI based on matrix size

S. No	1	2	3	4	5	6	7	8	9	10
RCI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

3.2 TOPSIS method

The TOPSIS was first developed by Hwang and Yoon (1981). TOPSIS is relatively simple and fast, with a systematic procedure (Shanian & Savadogo, 2006). It is proven as one of the best methods in addressing the rank reversal issue. The basic idea of TOPSIS is that the best decision should be made to be closest to the ideal and far from the non-ideal. Such ideal and negative-ideal solutions are computed by considering the other over all alternatives by Ertuğrul and Karakaşoğlu. (2009). Procedural steps involved in TOPSIS method are detailed in fig. 3.

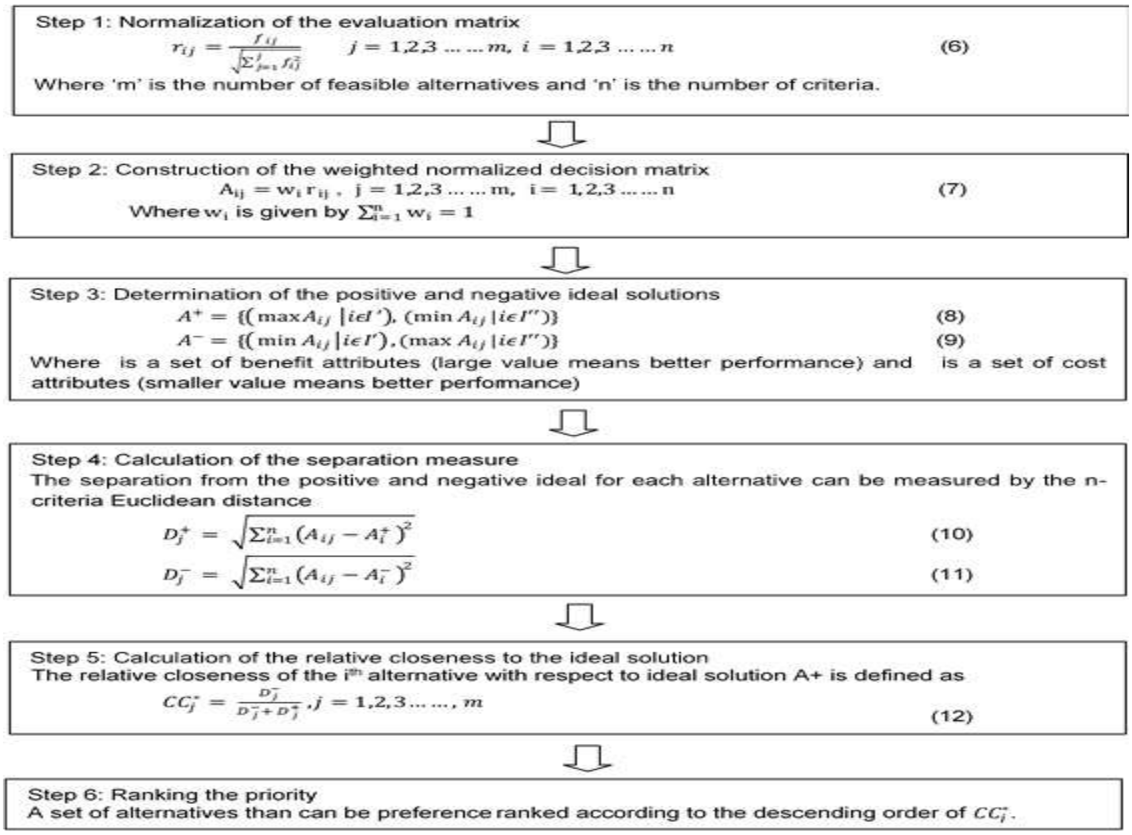

Fig 3: Stepwise procedure of TOPSIS

4. Proposed methodology

The proposed methodology consists of three basic stages: (1) Identification of the criteria to be used in the model. (2) AHP computation (3) Ranking the alternatives using TOPSIS. The schematic diagram of the proposed methodology for the selection of alternative maintenance strategy is shown in (Fig. 2). In the first stage, maintenance strategy alternatives and the evaluation criteria are identified and a decision hierarchy is constructed. The AHP model is structured such that the Goal is at the first level of the hierarchy; criteria and sub-criteria are at the second level; alternative strategies are on the third level. The decision hierarchy is approved by a decision-making team at the end of the first stage. In the second phase, the experts are given a task to construct the pair wise comparison matrices using Saaty's nine point scale. The criteria weights and the weights of interdependencies of sub-criteria are computed in this stage. In the third phase, strategy ranks are determined by TOPSIS method.

5. Numerical examples of the proposed model

In this section, a numerical example is applied to explain how the maintenance strategy selection decisions are made using the proposed model. This study is applied to a pump in paper industry which is located in the southern part of India. The critical equipment such as conveyor, digester, motors, pumps, refiners and rolling stock are playing an imperative role in paper production. Among which pumps are playing a predominant role for sucking and pumping the raw pulp from one place another place.

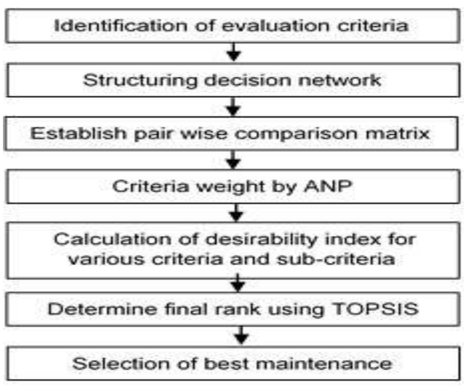

Fig 2: The proposed evaluation model for maintenance strategy selection

The maintenance engineer and supervisor are often facing failures of the pump due to shaft misalignment and bearing wear, excessive vibration to the pump, restricted discharge flow, cavitation and leakage of hazardous gases and they are willing to evaluate an optimum maintenance strategy for avoiding the aforementioned failures of the pump. The paper proposes the evaluation criteria and alternative strategies for selection of optimal maintenance strategies based on literature through Kirubakaran and Ilangkumaran (2016).

5.3 AHP Computations

The decision hierarchy diagram is established using identified evaluation criteria and the alternative strategies are shown in the Fig. 1. After the construction of the hierarchy diagram of the problem as mentioned, the AHP methodology requires the pairwise comparison of the criteria in order to determine their relative weights. In the pair wise comparison process, each criterion is compared with others using Saaty's nine point Scale. The pair wise comparison and weights of criteria, sub criteria and alternatives were calculated and as shown in Table 2, 3, 4 and 5 respectively.

Table 2. Eigen vector of comparison matrix for dependencies in various criteria

Goal	Safety	Cost	Added Value	Feasibility	Eigen vector	λ_{max}, CI, CR
Safety	1	5	4	3	0.539	$\lambda_{max} = 4.177$ $CI = 0.059$ $CR = 0.065$
Cost	1/5	1	1/2	1/3	0.085	
Added Value	1/4	2	1	2	0.201	
Feasibility	1/3	3	1/2	1	0.175	

Table 3. Eigen vector of comparison matrix of the sub-criteria under criteria 'safety'

Safety	Personnel	Facilities	Environment	Eigen vector	λ_{max}, CI, CR
Personnel	1	2	2	0.500	$\lambda_{max} = 3$ $CI = 0$ $CR = 0$
Facilities	1/2	1	1	0.250	
Environment	1/2	1	1	0.250	

Table 4. Eigen vector of comparison matrix for relative importance of each strategy for sub-criteria 'personnel'

Personnel	CM	TM	CBM	PM	Eigen vector	λ_{max}, CI, CR
CM	1	1/2	1/3	1/4	0.100	$\lambda_{max} = 4.010$ $CI = 0.003$ $CR = 0.004$
TM	2	1	1/2	1/2	0.185	
CBM	3	2	1	1	0.346	
PM	4	2	1	1	0.370	

5.4 Evaluation of maintenance alternatives and determinations of the using TOPSIS

The TOPSIS method has proposed for the selection of a suitable maintenance strategy. The obtained data are tabulated from the AHP results in Table 5 and are normalized using equation 6. The positive and negative ideal solutions are calculated using equations 8 and 9 and are tabulated in Table 6. Then the distance of each material alternative from positive ideal and negative ideal solution are computed using equations 10 and 11. The computation of the relative closeness to the ideal solution are done by equation 12. Finally, according to the relative closeness to the ideal solution value, the ranks are preferred to the strategies and the obtained results are tabulated in Table 7.

Table 5. Results of AHP

Sub criteria	Global weights			
Personnel	CM	TM	CBM	PM
Facilities	0.029	0.055	0.102	0.109
Environment	0.121	0.030	0.053	0.053
Hardware	0.011	0.023	0.054	0.060
Software	0.002	0.002	0.010	0.016

Personnel Training	0.001	0.001	0.004	0.011
Replacement	0.003	0.005	0.002	0.001
Spare Parts Inventories	0.003	0.001	0.001	0.001
Production Loss	0.005	0.013	0.023	0.023
Fault Identification	0.011	0.004	0.002	0.002
Acceptance By Labours	0.003	0.005	0.011	0.016
Technique Reliability	0.006	0.006	0.002	0.001
Procedure	0.008	0.016	0.034	0.063
Maintainability	0.002	0.002	0.012	0.014
Personel	0.004	0.023	0.023	0.012
AHP Ranking	0.209	0.186	0.333	0.380

Table 6. Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS)

PIS	NIS
0.084	0.023
0.052	0.013
0.044	0.008
0.012	0.100
0.006	0.062
0.005	0.031
0.004	0.019
0.020	0.088
0.006	0.038
0.016	0.048
0.012	0.002
0.113	0.014
0.025	0.004
0.007	0.044

Table 7. Comparison results of AHP and ANP-VIKOR

Alternatives	ANP-TOPSIS	
	Performance	Rank
CM	0.49	3
TM	0.46	4
CBM	0.53	2
PM	0.57	1

6. Results and Discussion

The results obtained through the proposed methodology AHP-TOPSIS are tabulated in Table 7. Predictive maintenance strategy alternative has obtained the highest performance value of .057 and which is selected as the best maintenance strategy among four alternatives. CBM, CM, TM have positioned at the second, third and fourth ranks with the final performance values of 0.53, 0.49, 0.46. The ranking order of the maintenance strategy alternatives of the proposed model is PM>CBM>CM>TM. But the topsis method requires lengthy calculations to obtain the ideal and negative ideal solution of the criteria and separation measures and the closeness coefficients of the alternatives. The computational timing is more, if the number of alternatives and the criteria increase. The Application of hybrid VIKOR is providing valuable assistance for selection of optimum maintenance strategy in complex decision-making problems.

7. Conclusion

The appropriate maintenance strategy selection is the strategic issue and may adversely affect the availability and reliability levels of plant equipment. Several maintenance strategy alternatives are to be considered and evaluated respect to different influencing criteria under the consideration of subjective data. Therefore, effective decision making approach is essential for the selection of maintenance strategy alternatives. The objective of this research is to propose a decision making approach for maintenance strategy selection through ANP-TOPSIS. AHP is used to compute the evaluation criteria weights whereas TOPSIS is employed to determine the final ranking of maintenance alternatives. The proposed models are applied to a case study and the steps of the decision making process are illustrated. The model has significantly increased the efficiency of the decision making process in the maintenance strategy selection problem. For further research, group decision making approaches can be developed using various MCDM techniques such as Fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Fuzzy VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) for selecting the best maintenance strategy.

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