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Decision Making of Condition Monitoring using AHP and TOPSIS Method.

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***Abstract:** In today's maintenance era various techniques are used for prevention of breakdown in mechanical engineering. Condition Monitoring Technique selection is a challenging job. MCDM can be useful in selecting between different methods. In this paper attempt is made to use GTMA and TOPSIS for comparing the various CM techniques. Attributes like Diagnostic Quality, Quantity of failure which can be measured, Cost, Supportability of diagnostic method and Environmental interference are used for current study. From the analysis is observed that ferrography and vibration analysis are the two most important techniques among various CM techniques.*

***Index Terms:** CBM, MCDM, GTMA, TOPSIS.*

I. INTRODUCTION

Multiple Criteria Decision Making (MCDM) techniques usually involve the decision-maker to assess options with regard to the criteria for the decision and also to assign the criteria weights of significance. Then the best option can be chosen based on the allocated weights. However, it often occurs after a choice is made that the decision-maker becomes dubious as to whether the correct weighting has been allocated to the criteria given that a range of eventualities can happen in the near future. This paper's primary objective is to tackle this issue and enhance the implementation of MCDM techniques by addressing possible changes in the weighting of criteria. Condition Monitoring is the method of controlling a parameter or situation (vibration, oil, temperature, sound pressure and acoustic signal) in the scheme to indicate a developmental failure. It involves three main steps; data acquisition, processing, and interpretation. Condition Monitoring gathers the raw data to be processed using signal processing methods to obtain the diagnostic information in the form of characteristics. Among the available methods, vibration analysis, acoustic signal analysis and lubrication oil analysis are widely used in rotating equipment fault diagnosis.

Selection of Condition monitoring is a difficult task. MCDM can be very helpful for selection among various techniques.

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II. LITERATURE SURVEY:

Multiple-criteria decision-analysis (MCDA) also known as multiple-criteria decision making (MCDM) is an operational research sub-discipline that clearly assesses various conflicting requirements in decision-making [1]. In Triantaphyllou's book on multi criteria decision making topic, some of the MCDM techniques in this category were explored in a comparative way. [2] Rao [3] used GTMA to develop a scheme of performance assessment for technical educational organizations that is used to rank technical institutions. Graph theory matrix method is used with various and interrelated characteristics to model and solve a decision-making issue. In our daily life, we mainly implicitly weigh various requirements and we might be satisfied with the implications of decisions on the basis of perceptivity alone [4]. Kaur et al. [5] proposed an index of Supply Chain Coordination to assess several processes of cooperation. To find the reliability of a mechanical hydraulic component, Gandhi and Agrawal [6] proposed a graph theory matrix approach. Graph theory has represented a major objective in system data analysis, network analysis, functional depiction, mathematical modeling, prognosis, etc. As proposed by Rao [7], graph theory has demonstrated its mettle in different areas of science and technology. Grover and Agrawal [8] constructed a TQM index to quantify the level of application of TQM approaches in an industrial sector. Upadhyay [9] proposed a systematic method for analyzing object-oriented software systems that is helpful to prevent drawbacks in the quality of the life cycle of software development. Yager [10] addressed the use of monotonic strategies in multi-criteria decision-making to reflect critical data. It demonstrates that the Choquet integral offers a suitable technique for combining the satisfaction of the individual requirements in cases where a measure expresses the connection between the significance of the criteria. N. Tandon et.al. [11] Constructed certain condition surveillance methods for detecting defects induction ball bearings of engine. R.M.Ayo-Imoru and A.C.Cilliers [12] presents a study on the present scenario of condition-based monitoring in the nuclear industry for maintenance. It is accomplished through a systematic examination of the main CBM stages of surveillance, diagnosis and prognosis. A methodical review on these dimensions of CBM has been carried out. It covers present nuclear industry practices and continuing research on the various techniques and techniques being developed.

III. CLASSIFICATION OF MCDM METHODS:

Most of the MCDM techniques used to this day. However, a rigorous categorization is needed for these techniques, which are quite extensive. When reviewing the associated journals; the MCDM techniques are categorized according to the criteria, possibilities, or solution features set in the decision problem framework. MCDM classification is mentioned below.

Four basic categories of Multi criteria problems are

- Selection between alternatives: Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), MAUT, Utility Additive Method, Measuring attractiveness by a categorical-based evaluation technique, PROMETHEE, TOPSIS, Objective Programming, Data Envelopment Analysis
- Alternatives Rating: AHS, AAS, MAUT, UTA, MACBETH, PROMETHEE, ELECTRE III, TOPSIS
- Alternatives Classification: AHS Sort, UTADIS, Flow sort, ELECTRE-Tri;
- Identifying Alternatives: GAIA and FS-Gaia.

In a process where there are many factors, such as contradictory criteria, alternatives and solutions, naturally, it will be both more challenging and lengthy to solve the MCDM problems. Here are a series of techniques that academics have established to fix issues with such decisions. These techniques usually assess the problem's solutions within some criteria and assist determine the most appropriate option.

It is possible to categorize the MCDM techniques in many distinct respects. Hwang and Yoon made a common categorization in 1981. MCDM approaches are gathered by Hwang and Yoon (1981) in two groups as multi-purpose decision-making (MPDM) and multi-quality decision-making (MQDM) techniques based on distinct purposes and distinct information groups. This classification style is expressed in Figure 1.

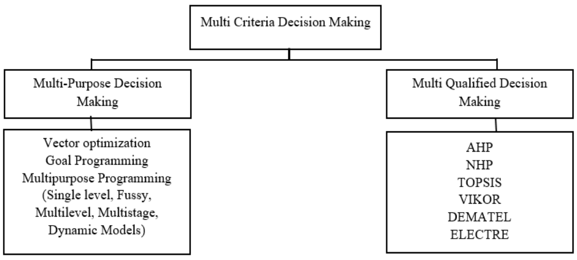

Figure 1: MCDM methods Classification

The difference between the two groups mentioned in the Figure 1 is the number of alternatives included in the effective solution in the decision issue. In other words, if there is an infinite number of a constant alternative in a decision problem, it can be considered as an MPDM technique if it contains limited and discrete alternatives that can be considered as an MPDM technique.

The techniques formulated considering the function of the solution route are considered necessary to be classified in the present classification of MCDM techniques that the research would like to highlight and see as a gap in the literature. MCDM techniques are categorized by information, criteria, options or number of decision-makers up to this day. However, the analytical methods including the MCDM problem solving techniques also differ within themselves. In the present classifications, these differentiations should definitely take place.

IV. TOPSIS METHOD OF MCDM:

Similarity to Ideal Solution (TOPSIS) Technique for Order of Preference is a multi-criteria decision analysis method that was originally developed by Ching-Lai Hwang and Yoon in 1981.With further innovations in 1987 by Yoon and 1993 by Hwang, Lai and Liu. It is based on the notion that the selected option should have the smallest geometric distance from the Positive Ideal Solution and the longest geometric distance from the NIS. This is a method of punitive grouping that compares a set of options by defining criterion for weights in each, normalizing results for every criterion, and compute the geometric distance between each alternative and the ideal option, which for each criterion is the highest rating. TOPSIS assumes that the criteria increase or decrease monotonically. Normalization is generally needed because in multi-criteria issues, parameters or criteria often have incongruous sizes. Compensatory techniques such as TOPSIS enable trade-offs between criteria where it is possible to negate a bad outcome in one criterion by a good consequence in another. This offers a more realistic type of modeling than non-compensatory techniques, including or excluding alternative difficult cut-off alternatives. Relative importance can be assigned using strategies as shown in table no. 1

Description	Relative importance		
	a_{ij}	$a_{ji} = 1/a_{ij}$	$a_{ji} = 1\text{-}a_{ij}$
Two characteristics are equally crucial	0.5	2.000	0.5
One characteristic over the other is slightly more crucial	0.6	1.666	0.4
One characteristic is much more essential than the other.	0.7	1.428	0.3
One characteristic over the other is very crucial	0.8	1.250	0.2
One characteristic over the other is highly essential	0.9	1.111	0.1
One characteristic is more crucial than the other	1.0	1.000	0.0

Table 1: Attributes relative importance.

The TOPSIS process is carried out as follows:

Step 1: Normalized decision matrix calculation. (Table no. 8)

The calculation of the normalized value is as described:

$$r_{ij} = x_{ij} \sqrt{\sum_{j=1}^{n} X_{ij}^2} \quad i = 1, 2, 3... m, \; j = 1, 2, 3, ..., n. \qquad \textbf{Eq. (1)}$$

Step 2: Calculate the weighted normalized decision matrix (Table no. 9). The normalized weighted value v_{ij} is calculated as follows:

$V_{ij} = r_{ij} \times w_{ij}$ i =1, 2, 3... m & j = 1, 2, 3, ..., n.

Where w_j is the weight of the j^{th} attribute an

$\sum_{j=1}^{n} w_j = 1$.

Step 3: Determine the ideal positive (A^*) and ideal negative (A^-) solutions.

$$A^* = \{(\max v_{ij}/j \varepsilon C_b), (\min v_{ij}/ j\varepsilon C_c)\} = \{v_j^*/j = 1, 2, 3, m\} \qquad \textbf{Eq. (2)}$$

$$A^- = \{(\min v_{ij}/j\varepsilon C_b), (\max v_{ij}/ j\varepsilon C_c)\} = \{v_j^-/j = 1, 2, 3, m\} \qquad \textbf{Eq. (3)}$$

Step 4: Use the m-dimensional Euclidean distance to calculate the separation strides (Table no. 10). For each option, the separation steps from the favorable ideal solution and the negative ideal solution are as follows:

Euclidean distance from Ideal best Value S_i^+ =

$$\left[\sum_{j=1}^{m}(V_{ij}-V_j^{+})^2\right]^{0.5} \quad \textbf{Eq. (4)}$$

Euclidean distance from Ideal Worst Value $S_i^- =$

$$\left[\sum_{j=1}^{m}(V_{ij}-V_j^{-})^2\right]^{0.5} \quad \textbf{Eq. (5)}$$

Step 5: Calculate relative closeness to the optimal solution (Table no. 11).

$$RC_i^* = \frac{S_i^-}{S_i^* + S_i^-}, \ I = 1, 2 \quad \textbf{Eq. (6)}$$

V. GRAPH THEORY MATRIX APPROACH (GTMA)

The graph theory matrix method is adopted in the present studies to discover the ideal combination of operating parameters. Approach Graph Theory Particular Methodology enables by identifying the system and subsystem up to the component level to assess and understand the system as a whole. The mathematical model generated through graph theoretical method takes into account both the contribution of the characteristics themselves and the magnitude of the attribute dependence. For modeling and visual assessment, digraph representation is helpful. Matrix representation is useful in assessing the digraph model. Permanent feature describes the system. Permanent function index is the unique number that is useful for comparison, ranking, and ideal combination selection. The graph theory matrix method is divided into three parts:

(i) Representation of digraph
(ii) Representation of matrix
(iii) Representation of Permanent function (Table no. 6).

Digraph is a finite group of entities called vertices along with a finite set of targeted edges or arcs that are arranged vertices pairs [12]. In this work, digraph reflects the nodes and edges of the characteristics and their inter-dependencies. This Digraph is composed of a collection of nodes V = {vi}, with I = 1, 2, 3, 4…M and a set of edges D = {d_{ij}}. If a node i has a relative significance (as shown in Table no. 1) a directional line or arrow is drawn from node i to j (dij) over another node j. If node j has comparative significance over i then node j to i (dji) draws a directed edge.

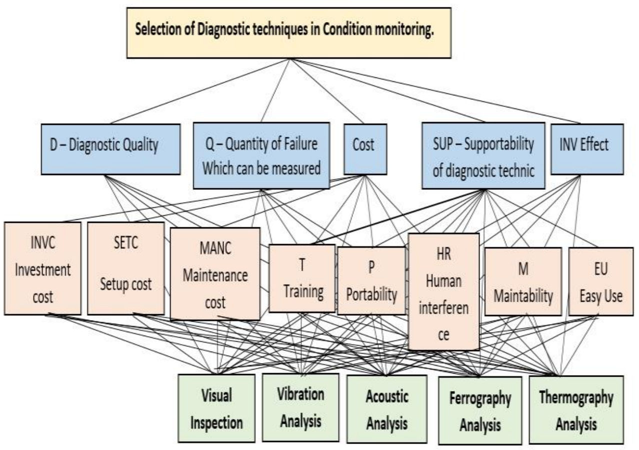

Figure 2: Diagraph representation of various attributes in CBM Techniques.

Matrix representation

A matrix presentation of a digraph is developed to reduce its complexity if the number of nodes is higher and the matrix representation also offers a one-to - one link between features and their relative meaning. If M nodes are included in the digraph, the attribute matrix is N X N in size. The characteristics are described as Ri diagonal components and the comparative significance of aij off diagonal components between characteristics. Digraph matrix characteristics are provided in Eq. (7).

$$A = \begin{bmatrix} R_1 & a_{12} & a_{13} & \cdots & \cdots & a_{1m} \\ a_{21} & R_2 & a_{23} & \cdots & \cdots & a_{2m} \\ a_{31} & a_{32} & R_3 & \cdots & \cdots & a_{3m} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{m1} & a_{m2} & a_{m3} & \cdots & \cdots & R_m \end{bmatrix} \quad \textbf{Eq. (7)}$$

From objective findings, Ri values are obtained. For these objective values, there will be separate units. Therefore, they must be standardized on the same scale as the subjective values, i.e. between 0 and 1. The relative value (aij) between characteristics can also be assigned a value between 0 and 1 on the scale shown in Table no. 1. The aji values are calculated using the Eq. (8) below.

$$a_{ji} = 1 - a_{ij} \text{ or } a_{ji} = 1/a_{ij} \quad \textbf{Eq. (8)}$$

VI. CONDITION MONITORING TECHNIQUES:

Condition monitoring has excellent ability to improve operational reliability, machine up-time, consequential harm decrease, and operational efficiency at reduced operating costs. Incipient faults in equipment are often defined by temperature differences, Vibro-acoustic signatures, etc. Various Methods of condition monitoring are described in Table no. 2.

Sr. No	Condition Monitoring Technique	Weakness	Improvement
1	Visual Inspection	• Unknown thresholds • External observations • Manually recorded • Less accurate	• Portable instruments with correction factors can be used to minimize error. • Warning system can be coupled with threshold
2	Vibration Based Analysis	• Undesirable signals • Unable to identify failure mode during flight. • Extreme temperature and humidity effects • Uncertainties in geometry, surface condition and loading	• Effective filter technique • Advanced mathematical modeling • Integrating failure data • Proper sensor placement
3	Acoustic Based Analysis	• Easy pick up of signals from unwanted sources. Sensor placement	• More powerful filter technique • Knowledge based systems • Coupling artificial intelligence
4	Wear Debris Analysis	• Offline analysis • Dry metal to metal contact. • Threshold detection Inability to differentiate foreign object damage with internal particle	• Applied data mining method for inflight analysis. • Method to detect very fine particles Indication for oil life (left)
6	Thermography and other NDT	• Offline analysis for mechanical defects • Environmental effect on surface temperature.	• Threshold generation through extensive data. • In-flight monitoring mechanisms

Table 2: Commonly used Condition Monitoring Techniques.

VII. METHODOLOGY:

For current study two methodologies i.e. GTMA and TOPSIS methods are used for comparison of various CBM methodologies. CBM techniques like Visual inspection, Vibration analysis, thermography, acoustic analysis and ferrography are used. Attributes like Diagnostic Quality, Quantity of failure which can be measured, Cost, Supportability of diagnostic method and Environmental interference are used for current study. Relative importance for each method is given using table no. 1. In TOPSIS analysis normalized matrix is used. By using normalized weighted values we calculate ideal positive and negative solutions, Euclidean distance from Ideal best Values are calculated by using equation 4 and 5. Ranking is given as per higher order of performance score. In GTMA method, digraph is drawn as shown in figure no. 2. Weighted normalized matrix is then solved for each CBM technique. Beneficiary and non-beneficiary criteria. Instead of finding determinant with negative sign, all positive sign are used and permanent function is calculated. Highest values of permanent function shows first ranking.

	D	Q	COST	SUP	ENV
D		0.7	0.3	0.5	0.5
Q	0.3		0.5	0.5	0.7
COST	0.7	0.5		0.6	0.6
SUP	0.5	0.5	0.4		0.5
ENV	0.5	0.3	0.4	0.5	

Table 3: Normalized values of attributes.

Beneficiary $\bar{X}_{ij} = X_{ij}/X_j^{max}$

Non beneficiary $\bar{X}_{ij} = X_j^{min}/X_{ij}$

	Beneficiary		Non beneficiary		
	D	Q	COST	SUP	ENV
Visual Inspection	1	2	1	1	5
Vibration Analysis	2	3	2	3	2
Acoustic Analysis	2	2	2	2	5
Ferrography Analysis	3	3	3	3	1
Thermography Analysis	2	2	3	3	5
X_j^{max}	3	3	3	3	5

Table 4: The attributes and the alternative weightage using five points scale in the decision making.

	Beneficiary	Beneficiary	Non beneficiary	Non beneficiary	Non beneficiary
	D	Q	COST	SUP	ENV
Visual Inspection	0.33	0.66	0.66	0.66	1
Vibration Analysis	0.66	1	0.33	1	0.6
Acoustic Analysis	0.66	0.66	0.33	0.33	1
Ferrography Analysis	1	1	1	1	0.8
Thermography Analysis	0.66	0.66	1	1	1

Table 5: Beneficiary and non-beneficiary values of attributes.

		D	Q	COST	SUP	ENV
Visual Inspection	D	0.33	0.7	0.3	0.5	0.5
	Q	0.3	0.66	0.5	0.5	0.7
	COST	0.7	0.5	0.66	0.6	0.6
	SUP	0.5	0.5	0.4	0.66	0.5
	ENV	0.5	0.3	0.4	0.5	1
Vibration Analysis		D	Q	COST	SUP	ENV
	D	0.66	0.7	0.3	0.5	0.5
	Q	0.3	1	0.5	0.5	0.7
	COST	0.7	0.5	0.33	0.6	0.6
	SUP	0.5	0.5	0.4	1	0.5
	ENV	0.5	0.3	0.4	0.5	0.6
Acoustic Analysis		D	Q	COST	SUP	ENV
	D	0.66	0.7	0.3	0.5	0.5
	Q	0.3	0.66	0.5	0.5	0.7
	COST	0.7	0.5	0.33	0.6	0.6
	SUP	0.5	0.5	0.4	0.33	0.5
	ENV	0.5	0.3	0.4	0.5	1
Ferrography Analysis		D	Q	COST	SUP	ENV
	D	1	0.7	0.3	0.5	0.5
	Q	0.3	1	0.5	0.5	0.7
	COST	0.7	0.5	1	0.6	0.6
	SUP	0.5	0.5	0.4	1	0.5
	ENV	0.5	0.3	0.4	0.5	0.8
Thermography Analysis		D	Q	COST	SUP	ENV
	D	0.66	0.7	0.3	0.5	0.5
	Q	0.3	0.66	0.5	0.5	0.7
	COST	0.7	0.5	1	0.6	0.6
	SUP	0.5	0.5	0.4	1	0.5
	ENV	0.5	0.3	0.4	0.5	1

Table 6: Permanent function for each CBM technique.

	Beneficiary	Beneficiary	Non beneficiary	Non beneficiary	Non beneficiary	Per (H)	Rank
	D	Q	COST	SUP	ENV		
Visual Inspection	0.33	0.66	0.66	0.66	1	0.116399	5
Vibration Analysis	0.66	1	0.33	1	0.6	3.585308	2
Acoustic Analysis	0.66	0.66	0.33	0.33	1	1.787543	4
Ferrography Analysis	1	1	1	1	0.8	6.288277	1
Thermography Analysis	0.66	0.66	1	1	1	3.015281	3

Table 7: Ranking between Various Condition monitoring Techniques by GTMA

	D	Q	Cost	SUP	EI
Visual	1	2	1	1	5
Vibration	2	3	2	3	2
Acoustic	2	2	2	2	5
Ferrography	3	3	3	3	1
Thermograph	2	2	3	3	5
$\sqrt{\sum_{j=1}^{n} x_{ij}^2}$	4.69041576	5.4772256	5.1961524	5.6568542	8.9442719

Table 8: Normalized Weighted Matrix for GTMA

Weightage	0.20	0.20	0.20	0.20	0.20
	D	Q	Cost	SUP	EI
Visual Inspection	0.2132007	0.3651484	0.1924501	0.1767767	0.5590170
Vibration Analysis	0.4264014	0.5477226	0.3849002	0.5303301	0.2236068
Acoustic Analysis	0.4264014	0.3651484	0.3849002	0.3535534	0.5590170
Ferrography Analysis	0.6396021	0.5477226	0.5773503	0.5303301	0.1118034
Thermography Analysis	0.4264014	0.3651484	0.5773503	0.5303301	0.5590170
	4.69041576	5.4772256	5.1961524	5.6568542	8.9442719

Table 9: Weighted Normalize matrix.

	D Diagnostic Quality	Q Quantity of Failure Which can be measured	Cost	SUP Supportability of diagnostic technic	EI Environmental Interference	S_j^+	S_j^-
Visual Inspection	0.0426401	0.0730297	0.03849	0.0035355	0.1118034	0.128865	0.35897703
Vibration Analysis	0.0852803	0.1095445	0.07698	0.0106066	0.0447214	0.062046	0.24908965
Acoustic Analysis	0.0852803	0.0730297	0.07698	0.0070711	0.1118034	0.112452	0.33533893
Ferrography Analysis	0.1279204	0.1095445	0.1154701	0.0106066	0.0223607	0.077304	0.27803617
Thermography Analysis	0.0852803	0.0730297	0.1154701	0.0106066	0.1118034	0.130872	0.36176215
V_j^+ Ideal (Best) Value	0.1279204	0.1095445	0.03849	0.0035355	0.0223607		
V_j^- Ideal (Worst) Value.	0.0426401	0.0730297	0.1154701	0.0106066	0.1118034		

Table 10: Euclidean distance from Ideal best Value.

S_i^+	S_i^-	$S_i^+ + S_j^-$	Performance Score $P_i = S_i^- / S_i^+ + S_j^-$	Rank
0.1288645	0.358977	0.4878415	0.735848	4
0.0620457	0.24909	0.3111353	0.800583	1
0.1124522	0.335339	0.4477911	0.748874	3
0.0773041	0.278036	0.3553403	0.78245	2
0.1308718	0.361762	0.492634	0.734343	5

Table 11: Performance Score and Ranking on GTMA

VIII. RESULT

From study of two methods mention above i.e. TOPSIS and GTMA it is observed that by assigning attributes to various condition monitoring techniques. We can rank the CBM methods easily. From above study, Ferrography technique stood in first rank with performance function 6.288277 (GTMA) and Performance score 0.800583 (TOPSIS) while Visual inspection is having lowest rank of 5 with performance function of 0.116399 (GTMA). In TOPSIS method Thermography analysis having lowest scale with performance score of 0.245748. Results of Both methods are tabulated in table no. 12.

Condition monitoring Techniques	GTMA	TOPSIS
	Rank	
Vibration Analysis	**2**	**1**
Ferrography Analysis	**1**	**2**
Acoustic Analysis	**4**	**3**
Visual Inspection	**5**	**4**
Thermography Analysis	**3**	**5**

Table 12: Ranking from GTMA and TOPSIS Methods.

IX. CONCLUSION

Well structuring complicated issues and explicitly taking into account various criteria leads to more informed and better choices. Important progress has been made in the area of decision making. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Graph theory matrix approach (GTMA) is used for comparing the various CM techniques. Attributes like Diagnostic Quality, Quantity of failure which can be measured, Cost, Supportability of diagnostic method and Environmental interference are used for current study. From the analysis is observed that ferrography and vibration analysis are the two most important techniques among various CM techniques.

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