Decision Making of Condition Monitoring using AHP and TOPSIS Method.

A. B. Gholap, M. D. Jaybhaye.

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 it 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.

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.

Revised Manuscript Received on August 05, 2019.

A. B. Gholap. Mechanical Engineering Department, Marathwada Mitra Mandal's college of engineering, Pune, India.
M. D. Jaybhaye. Department of Production Engineering and Industrial Management, College of Engineering, Pune, India.
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.

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.

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:

\[ r_{ij} = \frac{x_{ij}}{\sum_{j=1}^{n} x_{ij}} \]

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

\[ v_{ij} = w_{ij} \cdot r_{ij} \]

Step 3: Determine the ideal positive (A⁺) and ideal negative (A⁻) solutions.

\[ A⁺ = \{ \max v_{ij}/j \leq C_b \}, \min v_{ij}/j \leq C_b \} \]

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 $S^* = \left[ \sum_{j=1}^{m} (V_{ij} - V_{ij}^+)^2 \right]^{0.5}$ \hspace{1cm} \text{Eq. (4)}

Euclidean distance from Ideal Worst Value $S_i = \left[ \sum_{j=1}^{m} (V_{ij} - V_{ij}^-)^2 \right]^{0.5}$ \hspace{1cm} \text{Eq. (5)}

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

$$RC_i^* = \frac{S^*}{S_i} + S_i^*, \quad 1 = 1, 2$$ \hspace{1cm} \text{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 $V = \{v_i\}$, with $i = 1, 2, 3, \ldots M$ 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 (dij) draws a directed edge.

![Diagraph representation of various attributes in CBM Techniques.](image)

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 $N \times N$ in size. The characteristics are described as $R_i$ diagonal components and the comparative significance of $a_{ij}$ off diagonal components between characteristics. Digraph matrix characteristics are provided in Eq. (7).

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

From objective findings, $R_i$ 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 $(a_{ij})$ between characteristics can also be assigned a value between 0 and 1 on the scale shown in Table no. 1. The $a_{ij}$ values are calculated using the Eq. (8) below.

$$a_{ij} = 1 - a_{ij} \text{ or } a_{ij} = 1/a_{ij}$$ \hspace{1cm} \text{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.

| No. | Condition Monitoring Techniques | Weakness | Improvement |
|-----|--------------------------------|---------|-------------|
| 1   | Visual Inspection              | Unknown threshold, internal observations, manually recorded, less accurate | Portable instruments with correction factors can be used to minimize errors, warning system can be coupled with threshold |
| 2   | Vibration Based Analysis       | Uncontrollable signals, unable to identify failure mode during flight, extreme temperatures and humidity effects, uncertainty in geometry, surface condition and loading | Effective signal technique, advanced mathematical modeling, integrating failure data, proper sensor placement |
| 3   | Acoustic Based Analysis        | Easy pick up of signals from unattended sources, beam placement | More powerful signal technique, knowledge-based systems, coupling optical intelligence |
| 4   | Wear Debris Analysis           | Off-line analysis, dry soil to metal contact, threshold detection liability to differentiate foreign, object damage with internal particule | Applied data mining method for online analysis, methods to detect very fine particles indicating for oil life (mill) |
| 5   | Thermography and other NDT    | Off-line analysis for mechanical defect, environmental effect on surface temperature, | Threshold detection 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
Decision making of Condition monitoring using AHP and TOPSIS Method.

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.

Table 3: Normalized values of attributes.

| Beneficiary | Non-beneficiary |
|-------------|-----------------|
| D | 0.70 | 0.30 |
| Q | 0.33 | 0.50 |
| COST | 0.35 | 0.65 |
| SUP | 0.50 | 0.40 |
| ENV | 0.50 | 0.30 |

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

| Beneficiary | Beneficiary | Non-beneficiary | Non-beneficiary |
|-------------|-------------|-----------------|-----------------|
| D | 0.66 | 0.33 |
| Q | 0.66 | 0.33 |
| COST | 0.66 | 0.33 |
| SUP | 0.66 | 0.33 |
| ENV | 0.66 | 0.33 |

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

Table 6: Permanent function for each CBM technique.

Table 7: Ranking between Various Condition monitoring Techniques by GTMA

| Technique | D | Q | COST | SUP | ENV | Per (H) | Rank |
|-----------|---|---|------|-----|-----|---------|------|
| Visual Inspection | 0.18 | 0.46 | 0.66 | 0.66 | 1.26 | 1.01 | 5 |
| Vibration Analysis | 0.66 | 1 | 0.31 | 1 | 2.68 | 2.55 | 2 |
| Acoustic Analysis | 0.66 | 0.66 | 0.33 | 0.33 | 1 | 1.78 | 0.54 |
| Ferrography Analysis | 1 | 1 | 1 | 1 | 0.8 | 6.26 | 0.77 |
| Thermography Analysis | 0.66 | 0.66 | 1 | 1 | 1 | 3.04 | 2.84 |

Table 8: Normalized Weighted Matrix for GTMA

| Weightage | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
|-----------|------|------|------|------|------|
| D | 0.66 | 0.66 | 0.66 | 0.66 | 0.66 |
| Q | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 |
| COST | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 |
| SUP | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 |
| ENV | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 |

Table 9: Weighted Normalize matrix.

| D | Q | COST | SUP | ENV | Per (H) | Rank |
|---|---|------|-----|-----|---------|------|
| Visual Inspection | 0.66 | 0.33 | 0.66 | 0.33 | 1 | 1.26 | 0.65 |
| Vibration Analysis | 0.66 | 0.66 | 0.33 | 0.33 | 1 | 2.68 | 0.55 |
| Acoustic Analysis | 0.66 | 0.66 | 0.33 | 0.33 | 1 | 1.78 | 0.54 |
| Ferrography Analysis | 1 | 1 | 1 | 1 | 1 | 6.26 | 0.77 |
| Thermography Analysis | 0.66 | 0.66 | 1 | 1 | 1 | 3.04 | 2.84 |

Table 10: Euclidean distance from Ideal best Value.

| Sj | Sc | Sj + Sc | Performance Score | Rank |
|----|----|---------|-------------------|------|
| 0.128845 | 0.358977 | 0.487845 | 0.735440 | 4 |
| 0.0620457 | 0.24909 | 0.311135 | 0.890583 | 1 |
| 0.1214522 | 0.335339 | 0.457791 | 0.748874 | 3 |
| 0.0773041 | 0.278306 | 0.355430 | 0.782445 | 2 |
| 0.1308718 | 0.301762 | 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 CM 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 Rank | 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 methods.

REFERENCES

1. Madurika, HKGM, & Hemakumara, GPTS, “Gis Based Analysis For Suitability Location Finding In The Residential Development Areas Of Greater Matar Region”, International Journal of Scientific & Technology Research, 4(8), 96-105, (2015).
2. Triantaphyllou, E. “Multi-Criteria Decision Making: A Comparative Study. Dordrecht, the Netherlands”, Kluwer Academic Publishers. p. 320. ISBN 978-0-7923-6607-2, (2000).
3. R. V. Rao, “Graph Theory Matrix Approach for the Performance Evaluation of Technical Institutions”, Indian J. Tech. Edu., 23(2), 27-33 (2000).
4. Rew, L.”Intuition in Decision making”. Journal of Nursing Scholarship, Volume20, Issue3, September 1988, Pages 150-154, (1988).
5. A. Kaur, A. Kanda and S. G. Deshmukh, “A Graph Theoretic Approach for Supply Chain Coordination”, International Journal of Logistics Systems and Management 2(4):321-341 (2006).
6. O. P. Gandhi and V. P. Agrawal, “FMEA – A Digraph and Matrix Approach”, Reliability Engineering & System Safety, Volume 35, Issue 2, Pages 147-158, (1992).
7. R. V. Rao, “Decision Making in the Manufacturing Environment: using Graph Theory and Fuzzy Multiple Attribute Decision Making Methods”, Springer series in Advanced manufacturing, Volume 2, Springer, London (2013).
8. S. Grover and V. P. Agrawal, “A Digraph Approach to TQM Evaluation of an Industry”, International Journal of Production Research, 42(19), 4031-4053 (2004).
9. N. Upadhyay, “Structural Modeling and Analysis of Object Oriented Systems”, International Journal of Systems, Control and Communications, Volume 1, number 2, 240-255 (2008).
10. Ronald R.Yager, “Categorization in multi-criteria decision making”, Information Sciences, Volumes 460–461, Pages 416-423, (2018).
11. N. Tandon, G.S. Yadava, K.M. Ramakrishna, “A comparison of some condition monitoring techniques for the detection of defect in induction motor ball bearings”, Mechanical Systems and Signal Processing, 21, 244–256, (2007).
12. R.M.Ayo-Imoru, A.C.Cilliers, “A survey of the state of condition-based maintenance (CBM) in the nuclear power industry”, Annals of Nuclear Energy, Volume 112, Pages 177-188, (2018).

AUTHORS PROFILE

Mr. A. B. Gholap is presently working in Marathwada nitra Mandal College of Engineering Karvenagar Pune 52 as Assistant Professor. He is a graduate in Production Engineering from K. B. P. College of engineering Satara and M.E. in Production Engineering from Government College of Engineering, Karad. He joined MMCOE in the year 2016 and has been involved in the teaching for graduate student. His specialization includes Manufacturing processes, Industrial engineering. His experience also includes working as a Principal at ABIT polytechnic Satara and he worked as Depot Manager MSRTC Maharashtra. He has published 03 technical papers in international journals and conferences. He is a Fellow of Institution of Engineers (India) and Member of International Association of Engineers.

Dr. M.D. Jaybhaye is working currently as Associate Professor, Department of Production & Industrial Management at college of Engineering Pune. His qualification is B.E. (Production Engineering) in 1999, M.E. (Production Engineering) in 2002 and Ph.D. (Mech- Prod) in 2007. He has 16 years of teaching experience. He has published more than 28 papers in international Journals and conferences. His areas of interest are Robotics, Robot Dynamics & Analysis, Reliability Engineering, Project Planning & Control, and Computer Simulation & Analytical Tools. He has Memberships and Affiliations of LMISTE, LMORSI, LMTSI, AMIE, MIPE.