COMPARATIVE ANALYSIS OF AHP, TOPSIS, VIKOR & FUZZY-AHP FOR COMPUTERIZED MAINTENANCE MANAGEMENT SYSTEM SELECTION FOR MANUFACTURING INDUSTRIES

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ABSTRACT

Manufacturing industries in India are facing tough competition due to automation in maintenance, its increasing cost and uncertainties involved with the maintenance function. To eliminate maintenance problems, reducing downtime, enhancing productivity and cost optimization in any organization, proper selection and prioritization of Computerized Maintenance Management System (CMMS) criteria is the need of the hour. When CMMS criteria properly selected and implemented yields many benefits which include increased productivity, enhanced organizational achievements, improved safety, health & environment conditions and reduced costs of assets. CMMS is software installed to manage all the maintenance functions like planning, scheduling, managing, and tracking maintenance work orders associated with equipments and other facilities. A questionnaire was designed for the CMMS criteria identifications and an industrial survey was conducted. This paper presents a framework for the selection and prioritization of seven independent CMMS criteria with different multi-criteria decision-making methods like Analytical Hierarchy Process, Technique for Order Preference by Similarity to Ideal Solution, Vlse Kriterijuska OptimizacijaI Komoromisno Resenje and Fuzzy-AHP. Decision matrix is obtained from the field experts in the area of CMMS. Further, the rank prioritization of CMMS criteria is done with the above techniques. Moreover, and CMMS criteria are evaluated and compared to arrive at the final decision for the optimum selection of CMMS implementation in the industries. Comparison has been made between all the methods to validate the outcomes of the rankings of the important criteria. The results of the analysis determined the similar ranking patterns from the above techniques.

KEYWORDS: Computerized Maintenance Management System (CMMS), Manufacturing Industries, AHP, TOPSIS, VIKOR, Fuzzy-AHP and Multi-Criteria Decision Making

Received: Jun 06, 2020; **Accepted:** Jun 26, 2020; **Published:** Aug 24, 2020; **Paper Id.:** IJMPERDJUN2020859

1. INTRODUCTION

This paper toss light on CMMS criteria selection and prioritization for manufacturing industries with the help of different multi-criteria decision-making (MCDM) methods like Analytical Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Vlse Kriterijuska OptimizacijaI Komoromisno Resenje (VIKOR) and Fuzzy-AHP. These techniques are popularly used for the prioritization of the factors which influence the dependent variables like productivity improvement, overall organizational achievements, safety health and environmental improvement and cost optimization (Duran. O, 2011). Also, comparison has been made to analyze and validate the rankings of CMMS criteria. The outcome of this analysis corresponds to the weights of the factors chronologically having highest to lowest influence on the output factors.

Because of globalization, decreasing product life cycles, increasing product variety, changing technologies, fragmentation of supply-chain and an increased focus on sustainability companies have choices to make if they are to survive. (Saaty T et al., 1994) suggested AHP technique as a solution to the inconsistencies involved in the process of CMMS alternatives and criteria weights of perceived significance. (Hwang & Masud 2012) explained that when there are numbers of alternative with complex criteria (beneficial / non-beneficial and with different units), it is very difficult to make a transparent decision without favoritism. Some of the researchers have explained that in general decision making contains various alternatives, various criteria (objectives) and relative alternative performance with respect to criteria. MADM is technique to solve the multi attribute decision making (MADM) problems. MCDM and MADM are terms used interchangeably by various authors in the papers.

(Labib et al., 2004) conducted an examination into CMMS's characteristics, describing their shortcomings. The primary goal for this research was to selecting a best suited CMMS criterion that faces the organization's strategic analysis of criteria by using a multi criteria decision methods. A holonic concept (fixed rule and flexible strategy) was proposed in maintenance systems and applied the AHP technique for analysis highlighting CMMS characteristics and deficiencies present in existing model. (M. C. Carnero & J. L. Novés 2006) applied different methods like maximum eigenvalue, geometric averages and programming by goals for the selection of best CMMS out of 4 types of CMMS. The solutions found by these methods were same irrespective of the methods and the proposed model was applied in hospital only. (Braglia et al., 2006) combined AHP with a sensitivity study to enhance the feasibility of the approach and a technique has been suggested for the selection of the most suitable CMMS for industrial processes. (Andrés Gómez & María Carmen Carnero 2011) proposed a process for CMMS selection by applying multi-criteria decision-making technique ELECTRE-II in two stages. Firstly, for the software supplier's selection for successful implementation and secondly on the organizational need to best meet the demand in a Spanish regional health service. (Bertolini et al., 2006) applied AHP for the selection of public work contract with best discount.

(Rastegari. A 2016) used two methods for decision support are TOPSIS and k-means clustering technique for the selection of CMMS. This work is done in Sweden in large manufacturing industry to get new solutions regarding maintenance management. (Sinkkonen et al., 2013) have constructed a framework for only cost modelling from literature in first phase and practically collecting information from the respondents through interviews. Customer as well as maintenance service provider's opinions are collectively considered for the study to generate a win-win situation for an industry. (Rao 2007) explained that MADM technique works with four major stages (i) list of alternatives (ii) list of attributes (iii) calculation of the attribute weight and (iv) measurement of alternatives performance with respect to attribute weight. This study represents a CMMS selection framework where the accurate maintenance criteria are designed through the literature and suitable characteristics are mentioned using AHP, TOPSIS, VIKOR and Fuzzy-AHP for the assessment of CMMS.

The various Multi-Criteria Decision-Making techniques used for the prioritization of CMMS criteria are given below: Analytical Hierarchy Process (AHP); Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Vlse Kriterijuska OptimizacijaI Komoromisno Resenje (VIKOR) and Fuzzy-AHP. This study will also consider and focus on the main conflicting criteria of the assessment and comparisons of Computerized Maintenance Planning & Scheduling (CMPS); Computerized Material Management & Inventory Control (CMMIC); Computerized Report Management (CRM); Resource & Asset Management (RAM); Information Technology Management (ITM); Human Resource Development (Training) (HRDT); Overall Maintenance Capability Development (OMCD); Productivity Improvement (PI); Overall Organizational

Achievements (OOA), Safety, Health & Environment Improvement (SHEI) and Cost Optimization (CO).

The layout of rest of the paper is organized as Section 2 describes the related literature review. Section 3 elaborates the methodologies and analysis for prioritization of CMMS criteria like AHP, TOPSIS, VIKOR, and Fuzzy-AHP. This section also shows the details of calculations. Then comparisons between the methods of prioritization explained in Section 4. Finally, overall conclusion is presented in Section 5.

2. LITERATURE REVIEW

(Saaty et al., 1980) developed AHP, which is highly regarded and widely used decision-making method. AHP deals with tangible and non-tangible attributes and can solve unstructured and semi structured problems with multiple criteria inputs. It is based on matrices and their corresponding eigen vectors for generating approximate values of weights. The results of AHP method are widely used in many applications and are acceptable for prioritization of the criteria. Barbarosog et al., (2000), Kodali et al., 2001), Muralidharan et al., (1999), Tiwari et al., (2000), and Yang et al., (2003) applied AHP technique for vendor rating, customer performance, selection of casting process, production complexity and total productive maintenance set up in Indian industry. (Kahraman et al., 2003) developed Fuzzy-AHP for supplier selection in Turkey by taking the interviews of purchase managers. (Dozic & Kalic 2014) validated AHP methodology in aircraft selection process. (Kahraman et al., 2003) & (UmaDevi et al., 2012) worked on AHP for vendor selection. (Tugrul et al., 2012) applied AHP for third party logistics (3PL) provider's selection. (Vinodh et al., 2011) has implemented AHP concept in manufacturing field. (Can and Mucella, 2009) tried to implement Enterprise Resource Planning (ERP) based supplier selection with the help of AHP methodology. Flexible Manufacturing System (FMS) selection was carried out with Fuzzy AHP methodology by (Shamsuzzaman et al., 2003). (Cimren et al., 2007), (Lin and Yang, 1996) implemented AHP methodology in machine tool selection area. (Sayed et al., 2017) worked on agile method selection with AHP methodology. (Jiaqin & Huei 1997) applied AHP for facility location selection. (Lirn et al., 2004) implemented AHP methodology to transshipment problem selection. (Armilotta 2008) applied AHP in rapid prototyping layered manufacturing selection. As per (Nirmal & Bhatt 2019) and (Kahraman & Otay 2019), (Abdullah & Najib 2016) developed AHP with interval valued intuitionistic fuzzy set. (Czekster RM., et al., 2019) surveyed the literature and applied the popular AHP method for the selection of ERP (Enterprise Resource Planning) software for small and medium organizations to enhance productivity. (Deshmukh & Vasudevan 2019) applied supplier selection in plastic product manufacturing in MSME using AHP methodology. (Raut et al., 2017) applied AHP method for selection of sustainable warehouse location selection problem. (Jain & Khan 2016) applied AHP methodology for selection of reverse logistics provider's selection.

To overcome conventional AHP limitations, (Van Laarhoven & Pedrycz 1983) suggested Fuzzy-AHP method., a mixed approach of AHP and the Fuzzy theory. Fuzzy-AHP allows for the use of linguistic ratings in calculations by offering it some range. It is resolved that the decision-makers are more optimistic in giving judgments of interval than judgments of fixed value. (Lee 2009) implemented FAHP for determine suppliers, taking into consideration the opportunities, benefits, risks and costs. (NoorulHaq et al., 2006) suggested a structured vendor selection evaluation model using AHP and Fuzzy-AHP processes. (Mehdi, Hamid, and Hossein 2010) identified engineering partnerships using Fuzzy AHP. (Duran & Aguilo 2008) implemented Fuzzy-AHP in computer aided machine tool selection for ranking.

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) developed by (Chen & Hwang 1992a) prefers alternative approaches based on the shortest distance from the optimal solution and the farthest distance from the optimal situation. It is a technique of compensatory optimization which measures a number of alternatives through determining weight

for each criterion, then optimizing scores for each criterion, and determining the distance travelled between each alternative and the optimal alternative which seems to be the highest performance in each criterion. TOPSIS approach provides a Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS). PIS maximizes the value of the benefit criteria and NIS minimizes the cost criteria (non-beneficiary) or attributes. (Kumar et al., 2007) implemented TOPSIS for Third party logistics service provider selection. (Byun & Lee 2005) investigated modified TOPSIS in robotics selection. (Ic 2012) worked on computer integrated manufacturing technology selection using TOPSIS methodology. (Wei et al., 2019) worked on selection of manufacturing information system outsourcing by using TOPSIS methodology. (Fallahpour et al., 2017) developed decision support model for sustainable supplier selection using TOPSIS method. (Kolios et al., 2016) applied TOPSIS methodology for decision analysis of offshore wind turbine support structure. (Bianchini, 2018) proposed a model for third party logistics providers by combination of AHP and TOPSIS methodology.

Vise Kriterijuska Optimizacija Komoromisno Resenje (VIKOR) was explored by (Opricovic 1998), (Rao 2008b). (Opricovic 2015) applied VIKOR methodology in borrowing term selection. (Sahu & Mahapatra 2015) worked on VIKOR technique for selection of ergonomic design product with optimum set of design critical. (Jahan & Edwards 2013) applied VIKOR methodology where eleven alternatives and nine different attributes considered for material selection. (Geng & Liu 2015) implemented VIKOR methodology for supplier selection problem and for renewal energy project selection. (Dev et al., 2020) applied Entropy VIKOR method for automotive piston component material selection. (Singh et al., 2018) applied combination of AHP and VIKOR for selection of brake friction materials. (Fei et al., 2019) investigated Dempster-Shafer evidence theory (DS theory) with VIKOR method for supplier selection problem. (Arunachalam et al., 2015) applied AHP and VIKOR for polishing tool selection problem.

It is observed from the literature that AHP, TOPSIS, VIKOR and Fuzzy-AHP are popular in solving many prioritization problems and many applications in manufacturing industries as well as in other organizations to take the right decisions. Moreover, these four methods are implemented for solving the prioritization problem and for calculating the weights of CMMS criteria

3. METHODOLOGIES AND ANALYSIS FOR PRIORITIZATION OF CMMS CRITERIA

The different criteria of CMMS are compiled from the literature review and by structuring them into hierarchy and assess their relative importance and then finalized with some experts of the field.

3.1. Prioritizations with Analytical Hierarchy Process (AHP)

For selecting better CMMS criteria and to find out their weightage, AHP method is used for the prioritization. The AHP is a methodology developed by (Thomas Saaty in 1994) using a 9-point scale to rank alternatives in a decision process and is useful to get decision maker weights for use in TOPSIS. AHP method is applied to a complex problem by sub-dividing the parts hierarchically and then ranking the approaches and alternatives and lastly quantifying and comparing alternatives to generate a best possible solution. In this process of hierarchy, eleven factors considered for study (Table1). Out of eleven factors, first seven factors are mainly considered as input factors and last four factors are output factors as given in Table1. Seven factors are used as alternatives for the selection of best CMMS criteria to determine the priorities with AHP method and the priorities obtained communicate us that which criteria is more important and how much more on scale 1 to 9 between each other. A measurement scale provides the relative importance of each factor by providing numerical judgments corresponding to verbal ones. This scale is a discrete one and ranges from 1 to 9. Numeral 9 shows the highest importance

of one factor over other and 1 describing equal importance among two factors. AHP Scale used as: 1- Equal Importance, 3- Moderate importance, 5- Strong importance, 7- Very strong importance, 9- Extreme importance (2,4,6,8 values in-between). Similarly, for giving low importance to the criteria values between $\frac{1}{2}, \frac{1}{3}, \frac{1}{4}, \frac{1}{5}, \frac{1}{6}, \frac{1}{7}, \frac{1}{8}$ and $\frac{1}{9}$ are assigned (Saaty 1980). Pairwise comparison scales are used. There are few terminologies which are to be used again and again are defined and abbreviated in the following tables 1.

Table 1: The Abbreviations and Definitions used for Different Criteria of CMMS

S. No	Definition	Abbreviation
1	Computerized Maintenance Planning & Scheduling	CMPS
2	Computerized Material Management & Inventory Control	CMMIC
3	Computerized Report Management	CRM
4	Resource & Asset Management	RAM
5	Information Technology Management	ITM
6	Human Resource Development (Training)	HRDT
7	Overall Maintenance Capability Development	OMCD
8	Productivity Improvement	PI
9	Overall Organizational Achievements	OOA
10	Safety, Health & Environment Improvement	SHEI
11	Cost Optimization	CO

3.1.1. Sequence of Procedural Steps of AHP

First of all, criteria for AHP process is decided in which the numbers and names of criteria of CMMS were selected through literature for generating hierarchy between criteria and preferences are collected from the experts and are shown in Table 1. The Decision Matrix obtained from the experts given in table 2. This is the $m \times n$ matrix of the m alternatives by n attributes.

3.1.2. Pair-Wise Comparison (Decision Matrix) of Attributes:

While comparing attributes, the significance of j th sub-objective is calculated from with i th one. For seven numbers of variables in this study, a $[7 \times 7]$ matrix was prepared. This is known as decision matrix. In the matrix, the diagonal elements are kept 1 for equal importance. Values in upper matrix were filled by the field experts from different organizations. For lower triangular matrix, the upper diagonal values are reciprocated as $a_{ij} = \frac{1}{a_{ji}}$; Table 2 shows the Decision Matrix of pairwise comparisons for seven CMMS criteria.

After the pair wise comparisons to find out the priorities using AHP technique matrix is normalized. This is normalized by dividing all the element of the column by their column sum respectively. The Table 3 shows the normalized matrix with priority weights. The normalized value r_{ij} is calculated with given formula:

$$r_{ij} = \frac{a_{ij}}{\sum a_{ij}} \quad (1)$$

Further, the approximate value of priority weights ($w_1, w_2, w_3, \dots \dots w_j$) is obtained as:

$$w_j = \frac{1}{n} \sum a_{ij} \quad (2)$$

The outcome of the normalized matrix is shown in the Table 3. Then, normalized matrix with priority weights for seven CMMS criteria are shown in Table 3. Furthermore, the Table 4 elaborates about the calculations for prioritization with AHP method. Then, relative weights of elements are calculated by averaging the sum of the rows.

Table 2: Decision Matrix of Pairwise Comparisons of AHP

Criteria	CMPS	CMMIC	CRM	RAM	ITM	HRDT	OMCD
CMPS	1	1 / 2	9	1 / 2	3	1	2
CMMIC	2	1	9	2	5	5	7
CRM	1 / 9	1 / 9	1	1 / 9	1 / 7	1 / 7	1 / 5
RAM	2	1 / 2	9	1	7	7	7
ITM	1 / 3	1 / 5	7	1 / 7	1	1	2
HRDT	1	1 / 5	7	1 / 7	1	1	2
OMCD	1 / 2	1 / 7	5	1 / 7	1 / 2	1 / 2	1

3.1.3. Order of Ranks of CMMS Criteria Obtained with AHP Method:

The criteria's weighted score & Ranks obtained with AHP method is discussed in this section. Rank and the preference order according to the relative weightage of CMMS criteria are shown in tables 4. AHP weights are the sum of the weighted matrix row wise. Highest score ranked first and lowest score ranked seventh. The resulting weights are based on the principal eigenvector of the decision matrix. The Number of comparisons are 21, Consistency Ratio, CR = 6.8%, Principal Eigen value is 7.342 and Eigenvector solution obtained in 5 iterations, delta = 4.1E-8. The consistency ratio is the ratio of weighted sum and the criteria weight. The consistency Index comes out to be 0.0909 which is less than .10, therefore, this model is acceptable.

Table 3: Normalized Matrix with Priority Weights with AHP Method

Criteria	CMPS	CMMIC	CRM	RAM	ITM	HRDT	OMCD
CMPS	0.14400	0.18840	0.19149	0.12377	0.17004	0.06393	0.09434
CMMIC	0.28800	0.37679	0.19149	0.49509	0.28340	0.31963	0.33019
CRM	0.01600	0.04187	0.02128	0.02750	0.00810	0.00913	0.00943
RAM	0.28800	0.18840	0.19149	0.24754	0.39676	0.44749	0.33019
ITM	0.04800	0.07536	0.14894	0.03536	0.05668	0.06393	0.09434
HRDT	0.14400	0.07536	0.14894	0.03536	0.05668	0.06393	0.09434
OMCD	0.07200	0.05383	0.10638	0.03536	0.02834	0.03196	0.04717

**Table 4: Order of Ranks of CMMS Criteria with AHP Method
Highlighting the Weighted Sum and Ranks**

Criteria	AHP Weight	AHP Rank
CMPS	0.326370907	1
CMMIC	0.298552738	2
CRM	0.13942367	3
RAM	0.08837217	4
ITM	0.074657877	5
HRDT	0.053578211	6
OMCD	0.019044427	7

3.1.4. Elaboration of Perceived AHP Ranks:

Finally, priorities are established according to their relative weights. The standard procedure is followed for the calculations of weights of seven criteria in AHP method. Out of these seven criteria Computerized Material Management & Inventory Control perceived at rank one with 0.326370907 as performance score, Resource & Asset Management ranked second with score 0.298552738, Computerized Maintenance Planning & Scheduling has ranked third with score 0.13942367. Similarly, Human Resource Development (Training) is placed fourth with score 0.08837217 and Information Technology Management scored 0.074657877 achieved fifth rank. After that Overall Maintenance Capability Development and Computerized Report Management ranked sixth and seventh with score 0.053578211 and 0.019044427 respectively. Hence it is concluded from this discussion that Industries should give top priorities towards given criteria's such as Computerized Material Management

& Inventory Control, Resource & Asset Management and Computerized Maintenance Planning & Scheduling which achieved first, second and third ranking respectively. But it does not mean that remaining four criteria are not important. These should also be given due weightage to achieve the goal of the company towards CMMS. Table 6 shows Consistency Ratio of criteria's with AHP method. It is calculated by dividing weighted sum with the criteria weight. The Mathematical Formula of Consistency Ratio(C_R) is represented as:

$$\text{Consistency Ratio}(C_R) = \frac{\text{Consistency Index}(C_I)}{\text{Random index}(R_I)} \quad (3)$$

The maximum value of lambda ($\lambda_{\max}$ = 7.5453) is determined by averaging the consistency ratio column. The consistency index is denoted by CI and is calculated with the given equation.

$$\text{Consistency Index}(C_I) = \frac{\lambda_{\max} - n}{n-1} \quad (4)$$

Where n is the number of compared elements. The value of consistency index is found 0.0909. Consistency Ratio is calculated in excel spreadsheet which is considered as the ratio of consistency index and random index. If CR is less than 0.1 that is, 10 %, then judgments are considered to be consistent and acceptable.

From the Table 6, for seven ($N = 7$) number of criteria, random index value is 1.32. The maximum value of lambda ($\lambda_{\max}$) comes out to be 7.543 and the consistency index is 0.0909. Therefore, Consistency Ratio comes out to be .0689, which is less than .10; therefore, this model is acceptable for taking further decisions. The consistency test values are shown in Table 8. For 21 Number of comparisons, the Consistency Ratio (CR) obtained is 6.8 % and Principal Eigen value is 7.343 and the value of random index is chosen as for 7 numbers of criteria.

Table 7 shows the consistency ratio is calculated & checked to verify whether the calculated value correct or not for consistency. Consistency ratio calculated by dividing random index by consistency index. The values of Consistency Index obtained are 0.0909. The value for Random Index is taken from the Random Index Table which is 1.32 for seven numbers of criteria. Finally, Consistency Ratio is found to be 6.8 %. The observed value of Consistency Ratio (6.8%) is well below the .10 which is considered as standard value for comparison. Therefore, it is assumed that decision matrix is reasonably consistent so decision maker continues with the AHP for prioritization. Finally, priorities are established according to their relative weightage.

Table 5: Consistency Ratio of CMMS Criteria with AHP Method

Criteria	CMPS	CMMIC	CRM	RAM	ITM	HRDT	OMCD	Weighted Sum	Criteria Weight	C. Ratio
CMPS	0.1394	0.1632	0.1714	0.1493	0.2240	0.0884	0.1072	1.0428	0.1394	7.4793
CMMIC	0.2788	0.3264	0.1714	0.5971	0.3733	0.4419	0.3750	2.5639	0.3264	7.8559
CRM	0.0155	0.0363	0.0190	0.0332	0.0107	0.0126	0.0107	0.1380	0.0190	7.2450
RAM	0.2788	0.1632	0.1714	0.2986	0.5226	0.6186	0.3750	2.4282	0.2986	8.1334
ITM	0.0465	0.0653	0.1333	0.0427	0.0747	0.0884	0.1072	0.5579	0.0747	7.4727
HRDT	0.1394	0.0653	0.1333	0.0427	0.0747	0.0884	0.1072	0.6508	0.0884	7.3648
OMCD	0.0697	0.0466	0.0952	0.0427	0.0373	0.0442	0.0536	0.3893	0.0536	7.2660

Table 6: Random Index Values for Corresponding Number of Criteria

Number of Criteria (N)	1	2	3	4	5	6	7	8	9	10
Random Index (R_I)	0	0	0.58	0.89	1.12	1.24	1.32	1.41	1.45	1.49

Table 7: Consistency Test Values

Maximum Eigen Value	CI	RI	CR
7.343	0.0909	1.32	0.0689

3.2. Prioritizations with Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) Method:

TOPSIS Method is a Technique for order preference by similarity to ideal solution (TOPSIS), which is proposed by (Yoon; 1980), (Hwang & Yoon, 1981). This technique is used in a ranking method which is applied to find solution of Multiple Criteria Decision Making (MCDM) problem. The standard TOPSIS method is designed to find alternatives which have the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution but it does not consider the relative importance of these distances (Hwang & Yoon 1981; Yoon 1987). The positive ideal solution attempts to seek the maximization of benefit criteria and the minimum of the cost criteria that is non-beneficial, whereas the negative ideal solution is just the opposite. Moreover, when the solution is more similar to an ideal solution, the corresponding criteria will get a higher grade.

3.2.1. Sequence of Procedural Steps of Prioritizations with TOPSIS Method

Step 1: Establish a matrix of criteria & different alternatives by determining the objective and to identify the attribute values for each alternative. Let X_{ij} score of option i with respect to criterion j , where i denote the number of rows and j denote the number of columns.

$$X = (X_{ij})_{m \times n} \text{ matrix} \quad (5)$$

Step 2: This step involves the development of matrix formats. The row of this matrix is allocated to one alternative and each column to one attribute. The decided matrix is given as:

$$r_{ij} = \frac{X_{ij}}{(X_{ij}^2)}; \text{ for } i = 1, \dots, m; \text{ and } j = 1, \dots, n \quad (6)$$

Table 8 shows all these calculations of step 2 are shown as outcome in the following table given below. In this step all the elements of the matrix are squared. The following table shows the squared decision matrix for TOPSIS.

Table 8: Decision Matrix of Pairwise Comparisons of TOPSIS

Criteria	CMPS	CMMIC	CRM	RAM	ITM	HRDT	OMCD
CMPS	1	1/2	9	1/2	3	1	2
CMMIC	2	1	9	2	5	5	7
CRM	1/9	1/9	1	1/9	1/7	1/7	1/5
RAM	2	1/2	9	1	7	7	7
ITM	1/3	1/5	7	1/7	1	1	2
HRDT	1	1/5	7	1/7	1	1	2
OMCD	1/2	1/7	5	1/7	1/2	1/2	1

Table 9: Squared Decision Matrix for TOPSIS

CMMS Criteria	CMPS	CMMIC	CRM	RAM	ITM	HRDT	OMCD
CMPS	1	0.25	81	0.25	9	1	4
CMMIC	4	1	81	4	25	25	49
CRM	0.01235	0.01235	1	0.01235	0.02041	0.02041	0.04
RAM	4	0.25	81	1	49	49	49
ITM	0.11111	0.04	49	0.02041	1	1	4
HRDT	1	0.04	49	0.02041	1	1	4
OMCD	0.25	0.02041	25	0.02041	0.25	0.25	1

Sum of squares of column	10.37346	1.61275	367	5.32357	85.2704	77.27041	111.04
Sqrt of sum of squares	3.22079	1.26994	19.15724	2.30729	9.2342	8.79036	10.53755

Step3: Calculate the weight of the normalized decision matrix.

Step 4: Determine the positive ideal solutions and negative ideal solutions. Let VJ^+ be the set of benefit attributes or criteria (more is better) and VJ^- be the set of negative attributes or criteria (less is better). All these calculations of step-3 and step-4 are shown as outcome in the following table given below. Table 11 shows the weighted decision matrix for TOPSIS with ideal best solution and ideal worst solution,

Table 10: Normalized Decision Matrix for TOPSIS

CMMS Criteria	CMPS	CMMIC	CRM	RAM	ITM	HRDT	OMCD
CMPS	0.3105	0.1969	4.2282	0.1084	0.9746	0.1138	0.3796
CMMIC	1.2419	0.7874	4.2282	1.7336	2.7073	2.8440	4.6500
CRM	0.0038	0.0097	0.0522	0.0054	0.0022	0.0023	0.0038
RAM	1.2419	0.1969	4.2282	0.4334	5.3064	5.5743	4.6500
ITM	0.0345	0.0315	2.5578	0.0088	0.1083	0.1138	0.3796
HRDT	0.3105	0.0315	2.5578	0.0088	0.1083	0.1138	0.3796
OMCD	0.0776	0.0161	1.3050	0.0088	0.0271	0.0284	0.0949

Table 11: Weighted Decision Matrix for TOPSIS

CMMS Criteria	CMPS	CMMIC	CRM	RAM	ITM	HRDT	OMCD
Weights	0.1347	0.3326	0.0181	0.3103	0.0712	0.0831	0.0500
CMPS	0.0418	0.0655	0.0766	0.0336	0.0694	0.0095	0.0190
CMMIC	0.1673	0.2619	0.0766	0.5379	0.1928	0.2364	0.2325
CRM	0.0005	0.0032	0.0009	0.0017	0.0002	0.0002	0.0002
RAM	0.1673	0.0655	0.0766	0.1345	0.3778	0.4633	0.2325
ITM	0.0046	0.0105	0.0463	0.0027	0.0077	0.0095	0.0190
HRDT	0.0418	0.0105	0.0463	0.0027	0.0077	0.0095	0.0190
OMCD	0.0105	0.0053	0.0236	0.0027	0.0019	0.0024	0.0047
IDEAL BEST VJ^+	0.1673	0.2619	0.0766	0.5379	0.3778	0.4633	0.2325
IDEAL WORST VJ^-	0.0005	0.0032	0.0009	0.0017	0.0002	0.0002	0.0002

Step 5: Compute the distance for each alternative from the ideal solution. S_i^+ is a distance from the calculated values to the positive ideal solution and S_i^- is a distance from the calculated value to the negative ideal solution.

Step 6: Calculate the relative closeness to the ideal solution (relative proximity) and

$$(P_i = S_i^- / (S_i^+ + S_i^-)) \dots \dots \dots (7)$$

Step 7: Rank the preference order according to their relative proximity. Next Table12 shows Ranks of criteria's with TOPSIS method: in which Ranks are assigned by determining the performance score. The following table shows all these calculations of step-5, step-6 and step-7 as results.

Table 12: Order for Criteria According to Their Relative Proximity

CMMS Criteria	S_i^+	S_i^-	$S_i^+ + S_i^-$	P_i	Rankings
CMPS	0.78086	0.12589	0.90675	0.13884	3
CIMIC	0.29282	0.71204	1.00486	0.70860	1
CRM	0.86320	0.00000	0.86320	0.00000	7
RAM	0.44870	0.66204	1.11074	0.59604	2
ITM	0.84850	0.05108	0.89958	0.05678	5
HRDT	0.84216	0.05108	0.89324	0.05718	4
OMCD	0.85638	0.02343	0.87982	0.02663	6

3.2.2. Order of Ranks of criteria with TOPSIS Method:

According to the priority obtained from the calculation of performance score the chronological order of preferences of CMMS criteria are shown in the following Table 13. The standard procedure is adopted for the calculations of weights in TOPSIS method for the criteria of CMMS. The output of seven criteria exposed that Computerized Material Management & Inventory Control perceived at rank one with 0.724463 as performance score, Resource & Asset Management ranked second with score 0.64060, Computerized Maintenance Planning & Scheduling has ranked third with score 0.502987. Similarly, Human Resource Development (Training) is placed fourth with score 0.500431 and Information Technology Management scored 0.500425 achieved fifth rank. After that Overall Maintenance Capability Development and Computerized Report Management ranked sixth and seventh with score 0.500087 and 0.50000 respectively.

Table 13: The Chronological Order of TOPSIS Rankings

CMMS Criteria	Pi	Ranking
CMMIC	0.70860	1
RAM	0.59604	2
CMPS	0.13884	3
HRDT	0.05718	4
ITM	0.05678	5
OMCD	0.02663	6
CRM	0.00000	7

3.3. Prioritization with Visekriterijuska Optimizacijai Komoromisno Resenje (VIKOR) method

The VIKOR method is developed in 1998 by Opricovic, which stands for 'Vise Kriterijumska Optimizacija I Kompromisno Resenje,' meaning multi-criteria optimization and compromise solution (Opricovic et al., 1998). The VIKOR method is a technique of multiple criteria decision making (MCDM). Serafim Opricovic originally created it in 1998 to solve decision - making problems by conflicting and non-commensurable parameters (different units), on the assumption that compromise is appropriate for conflict resolution, that decision makers needed a solution closest to the objective and that alternatives are evaluated on all parameters. VIKOR classifies alternatives which are the seven CMMS parameters and selects a compromise solution which is the nearest to the optimal situation. In MCDM (Yu, 1973) and (Zeleny 1975), the principle of compromise was introduced. For converting the linguistic variables into the matrix, the five-point scale is used.

Table 14: Linguistic Variable and Assigned Number for VIKOR Method

Linguistic Variable	Assigned Number
Low	1
Below Average	2
Average	3
Good	4
Excellent	5

3.3.1. VIKOR method follows these sequences of standard procedural steps:

Step 1: Establish a matrix of criteria & different alternatives.

Step 2: Normalize the decision matrix

Step 3: Calculate the weight of the normalized decision matrix

Step 4: Determine the positive ideal solutions and negative ideal solutions

Step 5: Compute the distance for each alternative from the ideal solution

Step 6: Calculate the relative closeness to the ideal solution (relative proximity)

Step 7: Rank the preference order according to their relative proximity.

Table 16 shows VIKOR method is used for linear normalization where as TOPSIS method used for vector normalization.

Table 15: Decision Matrix for VIKOR Method

Criteria	CMPS	CMMIC	CRM	RAM	ITM	HRDT	OMCD
CMPS	1	1/2	9	1/2	3	1	2
CMMIC	2	1	9	2	5	5	7
CRM	1/9	1/9	1	1/9	1/7	1/7	1/5
RAM	2	1/2	9	1	7	7	7
ITM	1/3	1/5	7	1/7	1	1	2
HRDT	1	1/5	7	1/7	1	1	2
OMCD	1/2	1/7	5	1/7	1/2	1/2	1

Table 16: Normalized Decision Matrix for VIKOR Method

CMMS Criteria	CMPS	CMMIC	CRM	RAM	ITM	HRDT	OMCD
CMPS	0.31048	0.15524	2.79435	0.15524	0.93145	0.31048	0.62097
CMMIC	0.62097	0.31048	2.79435	0.62097	1.55242	1.55242	2.17338
CRM	0.03450	0.03450	0.31048	0.03450	0.04435	0.04435	0.06210
RAM	0.62097	0.15524	2.79435	0.31048	2.17338	2.17338	2.17338
ITM	0.10349	0.06210	2.17338	0.04435	0.31048	0.31048	0.62097
HRDT	0.31048	0.06210	2.17338	0.04435	0.31048	0.31048	0.62097
OMCD	0.15524	0.04435	1.55242	0.04435	0.15524	0.15524	0.31048
MAX	0.62097	0.31048	2.79435	0.62097	2.17338	2.17338	2.17338
MIN	0.03450	0.03450	0.31048	0.03450	0.04435	0.04435	0.06210

Table 17: Weighted Normalized Decision Matrix for VIKOR Method

CMMS Criteria	CMPS	CMMIC	CRM	RAM	ITM	HRDT	OMCD
CMPS	0.07134	0.18706	0.00000	0.24640	0.04153	0.07273	0.03676
CMMIC	0.00000	0.00000	0.00000	0.00000	0.02077	0.02424	0.00000
CRM	0.13474	0.33256	0.01811	0.31028	0.07120	0.08312	0.04999
RAM	0.00000	0.18706	0.00000	0.16426	0.00000	0.00000	0.00000
ITM	0.11889	0.29930	0.00453	0.30506	0.06230	0.07273	0.03676
HRDT	0.07134	0.29930	0.00453	0.30506	0.06230	0.07273	0.03676
OMCD	0.10700	0.32068	0.00906	0.30506	0.06749	0.07879	0.04411

3.3.2. Chronological Order of Ranks of CMMS criteria with VIKOR method: -

Table 18 shows Chronological Order of Ranks of CMMS criteria with VIKOR method. The calculations for S_i , R_i and Q_i at zero. The resultant ranks obtained from the calculations are shown in the following table.

Table 18: Chronological Order of Ranks of CMMS Criteria with VIKOR Method

CMMS Criteria	S_i	R_i	Q_i	VIKOR Rank
CMMIC	0.04501	0.02424	22.625	1
RAM	0.35133	0.18706	19.382	2
CMPS	0.65581	0.24640	16.139	3
HRDT	0.85201	0.30506	12.895	4
ITM	0.89957	0.30506	9.652	5
OMCD	0.93219	0.32068	6.408	6
CRM	1.00000	0.33256	3.165	7

3.4. Methodology based on Fuzzy-AHP method for the selection of the CMMS Criteria

Fuzzy-AHP method is used to calculate the weight of CMMS criteria. Decision Matrix for Fuzzy-AHP is collected from the experts (Kaganski et al., 2018). The weightage for calculation is taken from the analytical hierarchy process calculations. The standard procedure is followed for the calculation of Fuzzy Weights and then defuzzified number is taken for prioritization of CMMS criteria. The values in the scale of relative importance are crisp numeric values like 1, 3, 5, 7, 9 etc. in fuzzy. This method use these crisp numeric values and are converted into fuzzy number. Triangular membership function is used. The Fuzzy values which are assigned to the different numbers are given as follows in Table 19.

The standard technique is adopted for the calculations of weights in VIKOR method. The results of CMMS's seven criteria in VIKOR method showed that Computerized Material Management & Inventory Control perceived at rank one with 22.625 as performance score, Resource & Asset Management ranked second with score 19.382, Computerized Maintenance Planning & Scheduling has ranked third with score 16.139. Similarly, Human Resource Development (Training) is placed fourth with score 12.895 and Information Technology Management scored 9.652 achieved fifth rank. After that Overall Maintenance Capability Development and Computerized Report Management ranked sixth and seventh with score 6.408 and 3.165 respectively. Hence it is observed from the relative weights with VIKOR method, the criteria Computerized Material Management & Inventory Control is having the highest score as compared with the other criteria. Resource & Asset Management is preferred over Computerized Maintenance Planning & Scheduling. Likewise, Human Resource Development (Training) is preferred over Information Technology Management relatively. Lastly, Overall Maintenance Capability Development is preferred over Computerized Report Management because Computerized Report Management achieved the lowest value in the model for the organization.

Step 1: This is the matrix with Fuzzy numbers assigned for the crisp values given by the experts. Here fuzzified pair wise matrix was obtained by replacing all the crisp and reciprocal values with fuzzy numbers which are given in Table 20

Step 2: Fuzzy geometric mean is calculated for measuring the weights by the equation given below. This is achieved by multiplying all a, b, and c components of the rows and then taking seventh root for getting the desired Fuzzy geometric

$$r_i = \left\{ (a_1 * a_2 * a_3 * a_4 * a_5 * a_6 * a_7)^{1/7}, (b_1 * b_2 * b_3 * b_4 * b_5 * b_6 * b_7)^{1/7}, (c_1 * c_2 * c_3 * c_4 * c_5 * c_6 * c_7)^{1/7} \right\} = (a, b, c) \quad (8)$$

Step 3: The following formulae are used for calculation of weighted Fuzzified matrix.

$$w_i = r_i * (r_1 * r_2 * r_3 * r_4 * r_5 * r_6 * r_7)^{-1} \quad (9)$$

$$A^- = (l, m, u)^{-1} = \left(\frac{1}{u}, \frac{1}{m}, \frac{1}{l} \right) \quad (10)$$

Where $\frac{1}{u}$ correspond to the reciprocal of the upper value, $\frac{1}{m}$ correspond to reciprocal of the middle value and $\frac{1}{l}$ correspond to the lower value of the component of matrix. The fuzzified numbers are calculated by adding all a, b, c elements of the rows. Then defuzzified numbers are calculated by simply taking the average of the fuzzified number. Subsequently the ranks of the alternatives are determined for getting the best CMMS criteria out of the seven criteria.

Table 19: Fuzzy Values Assigned to the Different Crisp Variables

Number & Fuzzy Value	Reciprocal Number & Fuzzy Value
1= 1, 1, 1	1/2 = 1/3, 1/2, 1
2= 1, 2, 3	1/3= 1/4, 1/3, 1/2
3= 2, 3, 4	1/4= 1/5, 1/4, 1/3
4= 3, 4, 5	1/5= 1/6, 1/5, 1/4
5= 4, 5, 6	1/6= 1/7, 1/6, 1/5
6= 5, 6, 7	1/7= 1/8, 1/7, 1/6
7= 6, 7, 8	1/8= 1/9, 1/8, 1/7
8= 7, 8, 9	1/9= 1/9, 1/9, 1/9
9= 9, 9, 9	

Table 20: Fuzzy-AHP Decision Matrix from Experts

CMMS Criteria	CMPS	CMMIC	CRM	RAM	ITM	HRDT	OMCD
CMPS	1,1,1	1/3,1/2,1	9,9,9	1/3,1/2,1	2,3,4	1,1,1	1,2,3
CMMIC	1,2,3	1,1,1	9,9,9	1,2,3	4,5,6	4,5,6	6,7,8
CRM	1/9,1/9,1/9	1/9,1/9,1/9	1,1,1	1/9,1/9,1/9	1/8,1/7,1/6	1/8,1/7,1/6	1/6,1/5,1/4
RAM	1,2,3	1/3,1/2,1	9,9,9	1,1,1	6,7,8	6,7,8	6,7,8
ITM	1/4,1/3,1/2	1/6,1/5,1/4	6,7,8	1/8,1/7,1/6	1,1,1	1,1,1	1,2,3
HRDT	1,1,1	1/6,1/5,1/4	6,7,8	1/8,1/7,1/6	1,1,1	1,1,1	1,2,3
OMCD	1/3,1/2,1	1/8,1/7,1/6	4,5,6	1/8,1/7,1/6	1/3,1/2,1	1/3,1/2,1	1,1,1

Table 21: Fuzzified Geometric Mean Matrix

S. No	CMMS Criteria	Fuzzy Geometric Mean Value r_i		
1	CMPS	0.2857	1.9286	15.4286
2	CMMIC	123.4286	900.0000	3332.5714
3	CRM	0.0000	0.0000	0.0000
4	RAM	92.5714	441.0000	1974.8571
5	ITM	0.0045	0.0190	0.0714
6	HRDT	0.0179	0.0571	0.1429
7	OMCD	0.0003	0.0018	0.0238
Summation		216.30836	1343.00658	5323.09523

Table 22: Fuzzified Weights, Defuzzified Number and Ranks of CMMS Criteria with Fuzzy-AHP Method

S. No	CMMS Criteria	Fuzzified Weights			Defuzzified Number	Rank
1	CMPS	0.00005	0.00144	0.07133	0.02427	3
2	CMMIC	0.02319	0.67014	15.40658	5.36663	1
3	CRM	0.00000	0.00000	0.00000	0.00000	7
4	RAM	0.01739	0.32837	9.12982	3.15853	2
5	ITM	0.00000	0.00001	0.00033	0.00012	5
6	HRDT	0.00000	0.00004	0.00066	0.00024	4
7	OMCD	0.00000	0.00000	0.00011	0.00004	6

3.4.1. Result and Discussion of Fuzzy-AHP Method

The standard procedure is adopted for the calculations of weights in Fuzzy -AHP method. The output of seven criteria uncovered that Computerized Material Management & Inventory Control perceived at rank one with 5.366 as performance score, Resource & Asset Management ranked second with score 3.1585, Computerized Maintenance Planning & Scheduling has ranked third with score 0.02427. Similarly, Human Resource Development (Training) is placed fourth with score 0.00024 and Information Technology Management scored 0.00012 achieved fifth rank. After that Overall Maintenance Capability Development and Computerized Report Management ranked sixth and seventh with score 0.00004 and 0.0000 respectively. Hence from this argument it is observed that Industries should give top3 priorities towards given criteria's such as

Computerized Material Management & Inventory Control, Resource & Asset Management and Computerized Maintenance Planning & Scheduling which achieved first, second and third rank respectively. The other four criteria are less important. These criteria should be given due importance to achieve the global goal of the industry.

4. COMPARISON BETWEEN THE METHODS OF PRIORITIZATION

In this section, rankings of the CMMS criteria has been compared with the different methods such as AHP, TOPSIS, VIKOR and Fuzzy-AHP method. Comparison shown that the patterns obtained with the AHP, TOPSIS, VIKOR and Fuzzy-AHP method is same for all the seven criteria of CMMS. Therefore, decided decision matrix is acceptable for further decisions. It is predicted that the solution obtained for the rankings are similar and independent of the method applied for the prioritization which validate the rankings of criteria of CMMS with these MCDM methods.

Table 23 : Comparison of AHP, TOPSIS, VIKOR and Fuzzy-AHP Method

CMMS Criteria	AHP	TOPSIS	VIKOR	Fuzzy-AHP
CMPS	3	3	3	3
CMMIC	1	1	1	1
CRM	7	7	7	7
RAM	2	2	2	2
ITM	5	5	5	5
HRDT	4	4	4	4
OMCD	6	6	6	6

5. CONCLUSION

Hence by applying these qualitative techniques of multi-criteria decision making for CMMS criteria selection like AHP, TOPSIS, VIKOR and Fuzzy-AHP analysis, it is observed from the obtained relative weightage of the criteria that Computerized Material Management & Inventory Control is highest performance score as compared with the other criteria. Resource & Asset Management is preferred over Computerized Maintenance Planning & Scheduling. Likewise, Human Resource Development (Training) is preferred over Information Technology Management relatively and lastly, Overall Maintenance Capability Development is preferred over Computerized Report Management because Computerized Report Management achieved the lowest rank in the model. It is recommended that manufacturing industries should give top priorities towards given criteria's such as Computerized Material Management & Inventory Control, Resource & Asset Management and Computerized Maintenance Planning & Scheduling which achieved first, second and third ranking respectively. Also, comparison has been shown between the AHP, TOPSIS, VIKOR and Fuzzy-AHP methods and found that the results obtained are similar which validate the rankings of criteria of CMMS. It is observed that the solution obtained for the rankings are similar and independent of the method applied for the prioritization. Moreover, CIMMIC, RAM and CMPS emerged as top three CMMS criteria out of seven independent criteria.

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