Assessment of CNC Machine Tools using MCDM Techniques

Pramod A. Naik [1], Shivam Patil [2], D. N. Raut [3]

[1]Research Scholar, Department of Production Engineering, VJTI, Mumbai, India

[2]*M. Tech, II year student, Department of Production Engineering, VJTI, Mumbai, India*

[3]*Professor, Department of Production Engineering, VJTI, Mumbai, India*

Abstract *Manufacturing is the backbone of any industrialized nation and CNC machine is the integral part of any manufacturing industry. Selection of the optimal machine tool for manufacturing plant involves analysis of multiple conflicting factors, which increases complexity of the problem. Selection of appropriate machine tool is important as it involves a huge initial investment. Inappropriate machine tool may severely affect productivity of the factory. This paper presents multiple criteria decision making (MCDM) approach for the selection of suitable CNC machine tool. Weighted aggregated sum product assessment (WASPAS), Evaluation based on distance from average solution (EDAS), Combinative distance-based assessment (CODAS) and VIKOR methods are considered to evaluate CNC machine tools. Analytical hierarchy process (AHP) is applied to obtain criteria weights. All methods give quite similar ranking results. Results are also compared with other MCDM methods. Spearman`s rank correlation coefficient method is conducted to check the relation between methods.*

Keywords — *Multi-Criteria Decision Making (MCDM), CNC machine tool selection, WASPAS, EDAS, CODAS, VIKOR*

I. INTRODUCTION

Manufacturing is the backbone of any industrialized nation. Manufacturing technologies have continuously gone through revolutionary changes. We are in the fourth industry revolution, where traditional factory systems becoming smart systems, which can communicate with each other using internet. CNC machines are the main element of any manufacturing industry. New advanced CNC machines can fulfil current needs of the industry that is to produce highly customized products having high quality by communicating with other factory systems. CNC machines are undoubtedly be the hub because of their ability to control and communicate with other machines using internet. Many high and medium scale industries are not adopting new highly advanced CNC machine tools. But selecting suitable CNC machine is very important and also very difficult task as one need to consider various factors related to machine tool, workforce, inventory and factory layout before taking final decision. Cost associated with adopting new machine tools is very high. Inappropriate machine tool may lead to huge loss of money and productivity. In the manufacturing sector, management frequently faces the problem of evaluating alternative options and selecting one alternative for the job. Many times, management take decision based on previous experience, but decision based only on experience is not always effective. The use of scientific method while taking decision is always effective and efficient. There are several methods available, multiple criteria decision making is one of them. Multiple criteria decision making method can easily solve complex selection problems having any number of alternatives and criteria. MCDM refers to take decision under conflicting criteria. It has grown as part of operation research. In recent years, multiple criteria decision making has gained high popularity and has wide range of applications. This paper analyses some latest multi-criteria decision making methods namely, weighted aggregate sum product assessment (WASPAS), evaluation based on distance from average solution (EDAS), combinative distance-based assessment (CODAS) and VIKOR for CNC machine tool selection. Problem comprises of five CNC machine tool alternatives and six attributes. Among six attributes one is subjective attribute. The relative importance of attributes is calculated using analytical hierarchy process (AHP) with geometric mean normalisation method. In the final step ranking results of techniques are compared. Spearman`s rank correlation coefficient technic is used to compare ranking results.

II. LITERATURE REVIEW

S. Önüt et al. [3] used fuzzy based AHP-TOPSIS approach for machine tool selection. Triangular fuzzy numbers were considered with traditional method. Criteria weights were evaluated using fuzzy AHP and then ranking was obtained using fuzzy TOPSIS method. Sensitivity analysis was conducted by changing criteria weights. Chakraborty and zavadskas [4] explored applicability of WASPAS method for eight manufacturing decision making problems. They obtained accurate results with WASPAS method. M. Ghorabee et al. [5] applied EDAS method for multi criteria inventory classification. Usually, traditional ABC classification uses only one criterion, i. e. annual cost. Here, ABC classification of inventory is done based on three criteria. Result of proposed EDAS method is compared against different existing ABC inventory classification methods. S. Chakraborty et al. [6] applied WASPAS method for five manufacturing related problems, FMS selection, Machine selection in FMC, AGV system selection, Automated inspection system selection and Robot selection problems. Applicability of method was validated using these five problems. Ranking was also studied by varying λ values to check robustness of method.

S. Chakraborty et al. [7] proposed WASPAS method for Non-traditional machining process optimization. They applied method for selecting optimal process parameter combination for five non-traditional machines, ECDM, EDM, USM, LBM, WEDM. Also, optimal values of coefficient were determined which increased accuracy of the method. Prasad and Chakraborty [8] developed quality function deployment (QFD) technique for selecting CNC turning centre. System starts with accepting customer demands, then assigning weights, choosing criteria and accepting values for criteria, then shortlisting alternatives, providing rank list and details of the best solution. This automated process was developed in Visual 6.0. Some real time problems were discussed in paper. J. Kumar et al. [9] used TOPSIS and VIKOR approach for machine tool selection. Ranking results were compared with results obtained from SDI software tool. MINITAB software was used to measure correlation coefficient between two methods and result showed that both methods correlated each other. M. Yazdani et al. [10] proposed SWARA, QFD and WASPAS an integrated approach for the supplier selection. This approach was implemented in Steel company in Iran, where SWARA-QFD integrated method was used for weight calculation and ranking of six alternatives was done using WASPAS. Stability was checked by changing λ values. M. Madic et al. [11] applied WASPAS method for selecting optimal process condition for laser cutting operation. Alternatives and criteria were defined after conducting experiments based on Taguchi design. Relative weights of criteria were evaluated using AHP method. Stability of ranking of alternatives was checked using operational competitiveness ratings analysis (OCRA) method. Close correlation was found between rankings obtained by WASPAS and OCRA methods.

M. Ghorbaee et al. [12] presented CODAS multi criteria decision making method and applied the same for industrial robot selection problem and evaluation of microclimate in an office. Comparative sensitivity analysis using ten different sets of criteria weights was also performed to validate the proposed method. Venkateswarlu and Sharma [13] applied SAW and VIKOR methods for the selection of equipment. A case study was conducted in spring manufacturing company. Five alternatives were evaluated against five criteria. Decision makers initially used linguistic terms to rate alternatives under each criterion, then using scale linguistic terms were converted into crisp format and used those values were considered for further calculations. D. Panchal et al. [14] employed fuzzy AHP-CODAS approach for choosing optimal maintenance strategy in fertilizer industry. Five maintenance strategies were shortlisted for maintaining ammonia synthesis unit of urea. Total seventeen criteria grouped under six main criteria were considered for evaluating maintenance strategies. Sensitivity analysis confirmed the stability of proposed method.

M. Mathew and S. Sagar [15] compared different MCDM techniques while solving material handling equipment selection problem. They applied CODAS, EDAS, MOORA AND WASPAS methods for two problems, conveyor selection problem and automated guided vehicle selection problem. Ranks obtained by all methods were same and spearman correlation coefficient indicated strong correlations among methods. Sennaroglue and Celebi [16] used MCDM for location selection problem for military airport location. Weights were calculated using AHP method and the best location was selected by comparing results of two outranking methods, PROMETHEE and VIKOR. They also compared results with other MCDM techniques and carried sensitivity analysis on weights. H. Gupta [17] used multi criteria approach to evaluate service quality of Indian airline industry. Attributes categorised into seven main and twenty-nine sub-categories for analysis. He used best worst method for calculating weights of attributes and VIKOR method for outranking airlines. M. Yazdani [18] proposed MADM tool, WASPAS for hard magnetic material selection. Factor relationship (FARE) method was used to evaluate weights of criteria. Sensitivity analysis for validation of obtained results were also conducted using normalization tool and correlation coefficient. P. Sahoo et al. [19] implemented DOE and MCDM approach for the selection of optimal machining parameter settings. Hybrid Response surface method (RSM) with WASPAS method was used.

N. Kundakcı [20] applied integrated approach using MACBETH and EDAS methods for evaluation of steam boiler of a textile company. Here, MACBETH method was used to evaluate weights of criteria and EDAS was used for alternative ranking. MACBETH was supported by software, where consistency was checked automatically. D. Karabasevic et al. [21] proposed EDAS method for personnel selection in IT industry. SWARA method was used for weight evaluation. Three decision makers were considered and ranking for all three was derived using EDAS method. CODAS model was used for supplier selection problem by I. Badi et al. [22]. A case study was conducted in steel making company, considering four criteria for the evaluation of the most appropriate supplier among six suppliers. Sensitivity analysis was conducted to demonstrate the stability of method. I. Emovon et al. [23] applied WASPAS method to enhance ship system maintenance. WASPAS was combined with SD method for risk assessment analysis by obtaining ranks of failure modes and maintenance strategy selection problem. Problem was also analysed using TOPSIS method to validate results. I. Badi et al. [24] also used CODAS approach for site selection of desalination plant. Problem comprised of five alternatives and five attributes. Weights were determined by experts. Sensitivity analysis was conducted to evaluate robustness for the selected alternative. F. Ecer [25] proposed Fuzzy AHP and EDAS integrated model for selection of third-party logistics provider. Proposed model was applied for supplier selection in a marble company, where eleven criteria were considered for the evaluation of four alternatives. Fuzzy theory was applied to remove uncertainties in group decision making process.

Dr. A. Sudha [26] used evaluation based on Distance from Average solution (EDAS) method for water management problem in Agriculture crops. Best crop was selected on the basis of minimum water requirement and a higher income considering both drip and flood type irrigation techniques. D. Schitea et al. [27] proposed fuzzy based WASPAS, EDAS and COPRAS methods for site selection problem. Fourteen criteria were selected for analysing four locations. Four decision makers were considered for assessing criteria. Same rankings were obtained using all three methods. Results were also matching with past researchers results. A. Maghsoodi [28] implemented integrated SWARA-CODAS approach with target-based attributes for cement material selection. Weights were calculated using SWARA method. Here, exponential target-based normalization technique was applied and then ranking was found using CODAS method. M. Moradian [29] compared MOORA, TOPSIS and VIKOR methods while solving material selection problem. Combined entropy and AHP methods were used to obtain criteria weights.methods were combined using Spearman`s rank correlation coefficient method. V. Pathapalli et al. [30] applied MOORA and WASPAS methods for machining parameter optimization. Criteria were decided based on experiments conducted using DOE. Criteria weights were evaluated using entropy method. ANNOVA was conducted to validate proposed experimental model by MOORA and WASPAS methods. Reddy and Anand [31] applied WASPAS and S/N ratio analysis to optimize WEDM process. Experiments were performed on aluminium metal matrix nano composite as per DOE. Entropy method was utilised for weight calculation. Obtained parameter set was confirmed experimentally, which validated proposed approach.

SWARA-WASPAS approach was used by Singh and Modgil [32] for the selection of cement supplier. A case study was conducted in Indian cement industry. Twelve criteria were analysed and weights were evaluated using SWARA method. The best supplier was selected with the help of WASPAS method. A. Ghaleb et al. [33] compared of three MCDM techniques while solving manufacturing selection problem. They evaluated five manufacturing processes to manufacture pump part using AHP, TOPSIS and VIKOR techniques. They concluded VIKOR as better in terms of computational complexity. Narad and Joshi [34] used AHP-EDAS approach to select optimum blend of fuel. Experiments were conducted using Chlorella Vulgaris as a biofuel with diesel. Eight blends were analysed using eight criteria. A. Roy et al. [35] used integrated entropy and CODAS method to select appropriate material for aerospace application. Problem comprised of nine material alternatives with seven criteria. Jayant and Singh [36] implemented integrated MOORA, SWARA and WASPAS approach for reverse logistics operation for the mobile phone company. SWARA method was used to calculate criteria weights and MOORA and WASPAS were used to obtain ranking of alternatives.

III. MCDM Method Formulation

A. VIKOR Method

The VIKOR (the Serbian name is 'VIse Kriterijumska Optimizacija kompromisno Resenje' which means multi-criteria optimization and compromise solution) method. Let, there are 'N' number of alternatives and 'M' number of criteria. The multiple attribute merit for compromise ranking was developed from L_p-metric used in the compromise programming method.

$$L_{p,i} - \left\{ \sum_{j=1}^{M} \left(w_j \left[(m_{ij})_{max} - (m_{ij}) \right] / \left[(m_{ij})_{max} - (m_{ij})_{min} \right] \right)^{p} \right\}^{1/p}$$

$$1 \le p \le \infty; i = 1, 2, \ldots, N$$

In VIKOR method $L_{1,i}$ and $L_{\infty,i}$ are used to formulate the ranking measure. R. V. Rao [1] described procedural steps for VIKOR method are as follows:
Step 1: Identify the objective and evaluation attributes. Also determine the best, i.e., $(m_{ij})_{max}$, and the worst, i.e., $(m_{ij})_{min}$, values of all attributes.
Step 2: Calculate the values of $L_{1,i}$ (E_i) and $L_{\infty,i}$ (F_i) using following formulae.

$$E_i = \sum_{j=1}^{M} w_j \left[(m_{ij})_{max} - (m_{ij})\right] / \left[(m_{ij})_{max} - (m_{ij})_{min}\right] \quad (1)$$

$$F_i = Max^m \text{ of} \left\{ \frac{w_j\left[(m_{ij})_{max} - (m_{ij})\right]}{\left[(m_{ij})_{max} - (m_{ij})_{min}\right]} \middle| j = 1, 2, \ldots, M \right\} \quad (2)$$

Step 3: Calculate the values of P_i using following formula.

$$v\left(\frac{(E_i - E_{i-min})}{(E_{i-max} - E_{i-min})}\right) + (1 - v)\left(\frac{(F_i - F_{i-min})}{(F_{i-max} - F_{i-min})}\right) \quad (3)$$

where E_{i-max} and E_{i-min} are the maximum and minimum values of E_i respectively, and F_{i-max} and F_{i-min} are the maximum and minimum values of F_i respectively. v is weight of the strategy of 'the majority of attributes'. The value of v lies in the range of 0 to 1. Normally, its value is taken as 0.5.
Step 4: Arrange the alternatives in the ascending order, according to P_i values. The best alternative is the one having the minimum P_i value.

B. WASPAS Method

The Weighted Aggregates Sum Product Assessment (WASPAS) method was introduced by Zavadskas, Turskis, Antucheviciene and Zakarevicius in 2012. It is a combination of weighted sum method (WSM) and weighted product method (WPM). Procedural steps of WASPAS method are as follows [4].
Step 1: Identify selection criteria and alternatives. Let, there are m is number of alternative and n is the number of criteria. Prepare decision matrix X = [x_{ij}].

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$$

Step 2: Obtained normalized decision matrix ($\bar{x}_{ij}$) using following formulae.
For beneficial criteria,

$$\bar{x}_{ij} = \frac{x_{ij}}{\max_i x_{ij}}$$

For non-beneficial criteria,

$$\bar{x}_{ij} = \frac{\min_i x_{ij}}{x_{ij}} \quad (4)$$

Step 3: Calculate additive relative importance of each alternative. Additive relative importance of i^{th} alternative is calculated as follows:

$$Q_i^{(1)} = \sum_{j=1}^{n} \bar{x}_{ij} w_j \quad (5)$$

where w_j represents weights of j^{th} criterion.
Step 4: Calculate multiplicative relative importance of each alternative using following formula:

$$Q_i^{(2)} = \prod_{j=1}^{n} (\bar{x}_{ij})^{w_j} \qquad (6)$$

Step 5: Calculate joint generalized criterion (Q) of weighted aggregation of additive and multiplicative methods using following generalized equation.

$$Q_i = \lambda\, Q_i^{(1)} + (1 - \lambda)\, Q_i^{(2)} \qquad (7)$$

where value of λ lies between 0 to 1. When λ is 0, WASPAS method becomes WPM, and when λ is 1, method becomes WSM.
Step 6: Arrange alternatives in descending order of joint generalized criterion values. Alternative with the highest joint generalized criterion value is the best solution for the problem.

C. EDAS Method

The Evaluation based on Distance from Average Solution or EDAS method, in which the best alternative is chosen by calculating the distance of each alternative from the optimal value [2]. Following is the procedure for EDAS for a problem involving n criteria and m alternatives as proposed by Sudha [26]:
Step 1: Select available alternatives and important criteria to construct decision matrix $D[x_{ij}]$.
Step 2: Determine the average solution (AV_j) according to all the criteria using formula:

$$AV_j = \frac{\sum_{i=1}^{n} x_{ij}}{n} \qquad (8)$$

Step 3: Calculate positive distances from average (PDA) solution using following formulae:

If j^{th} criterion is beneficial

$$PDA_{ij} = \frac{\max\left(0, \left(x_{ij} - AV_{ij}\right)\right)}{AV_j} \qquad (9)$$

If j^{th} criterion is non-beneficial

$$PDA_{ij} = \frac{\max\left(0, \left(AV_{ij} - x_{ij}\right)\right)}{AV_j} \qquad (10)$$

Step 4: Calculate negative distances from average (NDA) solution using following formulae:

If j^{th} criterion is beneficial

$$NDA_{ij} = \frac{\max\left(0, \left(AV_{ij} - x_{ij}\right)\right)}{AV_j} \qquad (11)$$

If j^{th} criterion is non-beneficial

$$NDA_{ij} = \frac{\max\left(0, \left(x_{ij} - AV_{ij}\right)\right)}{AV_j} \qquad (12)$$

Step 5: The weighted sum of PDA is obtained as:

$$SP_i = \sum_{j=1}^{m} w_j\, PDA_{ij} \qquad (13)$$

where w_j represents the weight of j^{th} criterion.
Step 6: The weighted sum of NDA is obtained as:

$$SN_i = \sum_{j=1}^{m} w_j\, NDA_{ij} \qquad (14)$$

Step 7: The normalized values of SP_i and SN_i for all alternatives are calculated as follows:

$$NSP_i = \frac{SP_i}{\max_i(SP_i)} \quad (15)$$

$$NSN_i - 1 - \frac{SN_i}{\max_i(SN_i)} \quad (16)$$

where NSP_i and NSN_i denote the weighted normalized sum of PDA and NDA respectively.
Step 8: Calculate appraisal score (AS_i) for all alternatives using following formula:

$$AS_i = \frac{1}{2}(NSP_i + NSN_i) \quad (17)$$

Where $0 \le AS_i \le 1$

Step 9: Rank alternatives in the descending order of appraisal score. The alternative with the highest appraisal score is the best choice among alternatives.

D. CODAS Method

Combinative Distance-based Assessment or CODAS method in which desirability of alternatives is determined using two measures [24]. Primary measure is the Euclidean distance and secondary measure is the Taxicab distance. CODAS procedural steps are as follows, given by I. Badi [24]:
Step 1: Construct the decision making matrix, $X = [x_{ij}]_{n \times m}$, where x_{ij} represents denotes the performance value of i^{th} alternative against j^{th} criterion. Decision matrix have n number of alternatives which are arranged row-wise and m number of attributes, arranged column-wise.
Step 2: Compute the normalized decision matrix using following equations.

$$n_{ij} = \frac{x_{ij}}{\max_i x_{ij}} \quad \text{if } j \epsilon N_b$$
$$n_{ij} = \frac{\min_i x_{ij}}{x_{ij}} \quad \text{if } j \epsilon N_c \quad (18)$$

where N_b and N_c represents the sets of beneficial and non-beneficial (cost) criteria, respectively.
Step 3: Compute weighted normalized decision matrix by using equation (19).

$$r_{ij} = w_j n_{ij} \quad (19)$$

where w_j represents the weights of j^{th} criterion.
Step 4: Determine negative-ideal solution for each criterion.

$$ns = [ns_j]_{1 \times m}$$
$$ns_j = \min_i r_{ij} \quad (20)$$

Step 5: Calculate the Euclidean distances (E_i) and Taxicab distances (T_i) of alternatives from negative ideal solution using following formulae:

$$E_i - \sqrt{\sum_{j=1}^{m} (r_{ij} - ns_j)^2} \quad (21)$$

$$T_i = \sum_{j=1}^{m} |r_{ij} - ns_j| \quad (22)$$

Step 6: Construct the relative assessment matrix as given below:

$$R_a = [h_{ik}]_{n \times n}$$
$$h_{ik} = (E_i - E_k) + (\psi(E_i - E_k) \times (T_i - T_k)) \quad (23)$$

Where $k \in \{1, 2, 3, \ldots, n\}$ and ψ denotes a threshold function to recognize the equality of the Euclidean.

$$\psi(x) = \begin{cases} 1 & \text{if } |x| \geq \tau \\ 0 & \text{if } |x| < \tau \end{cases} \quad (24)$$

τ is the threshold parameter that can be set by the decision maker. It is suggested to set this parameter at a value between 0.01 to 0.05. if the difference between Euclidean distances of two alternatives is less than τ, these two alternatives are also compared by the Taxicab distance.

Step 7: Calculate the assessment score of each alternative using following formula:

$$H_i = \sum_{k=1}^{n} h_{ik} \quad (25)$$

Step 8: Rank the alternatives according to the decreasing values of assessment scores. Alternative with the highest assessment score is the best alternative for problem.

TABLE 1 QUANTITATIVE DATA FOR CNC MACHINE TOOL SELECTION

CNC Machine Tool	Power	Operation Easiness	Cost	Spindle	Diameter	Floor Space
CMT1	15	0.335	4.5	5000	350	4.664
CMT2	22	0.41	5	3500	425	4.7925
CMT3	19	0.745	7	5000	420	5.04
CMT4	22	0.59	9.2	3500	500	6.48
CMT5	30	0.745	9.75	2000	590	6.96

IV. CNC MACHINE TOOL SELECTION PROBLEM

CNC machine tool selection problem is solved using four latest multi criteria decision making techniques – VIKOR, WASPAS, EDAS and CODAS. Five suitable CNC machine tools are shortlisted as per requirements of the factory. Based
on machine tool operator and previous research work, power, operation easiness, cost, spindle, diameter and floor space are selected as attributes to evaluate machine tool alternatives. Power (P) measured in kilowatts, is the amount of energy required for machine to successfully perform required operation. Operation easiness (OE) is the simplicity of machine to use. Effective ways to add or remove or edit programs. Cost (C) of machine consists total procurement cost. Spindle speed (SS) is the maximum rotational speed achievable by spindle. Diameter (D) is the maximum workpiece diameter that can be machined. Floor space (FS) is the floor area required for CNC machine tool and its supporting components. Among these six attributes, power, cost and floor space are non-beneficial attributes (less is better), remaining are beneficial attributes (more is better). Operation easiness is the only qualitative type attribute used in the problem, whose values are converted into numeric format using seven-point scale given in Rao [1].

TABLE 1 shows problem decision matrix that is the score of each alternative with respect to criterion. All the data is gathered from machine expert and machine broacher and information about machine tools available online. Criteria weights were estimated using analytical hierarchy process (AHP)
as explained in Rao [1]. Pairwise comparison matrix was created and geometric mean normalisation method was used to calculate criteria weights. Estimated criteria weights are $w_P = 0.3775$, $w_{OE} = 0.2887$, $w_C = 0.1686$, $w_{SS} = 0.0852$, $w_D = 0.0517$ and $w_{FS} = 0.0284$. These weights are consistent as CR value is 0.0577.

A. VIKOR Method

Values of Ei and Fi are calculated using equation (1) and (2) respectively. Alternatives ranked based on Pi values, which are evaluated using equation (3). Calculated values of Ei, Fi, Pi are as given in TABLE 2.

B. WASPAS Method

In this method, TABLE 1 is normalised using equation (4) as shown in

TABLE 3. Next is to calculate relative importance of alternatives. Additive relative importance is calculated using equation (5) given in step 3. Multiplicative relative importance of each alternative is calculated using equation (6).

Joint generalized criterion (Q) of weighted aggregation of additive and multiplicative methods is calculated using equation (7). Calculated values of relative importance and their joint generalized criterion are tabulated in

TABLE 4. While evaluating joint generalized criterion, value of λ is taken as 0.5. Final step is to rank all alternatives in descending order according to their joint generalized criterion values, as given in

TABLE 4.

C. EDAS Method

EDAS average solution according to criteria is obtained using equation (8) and given in TABLE 5. PDA solution for beneficial attributes and non-beneficial attributes are calculated using equation (9) and (10) respectively. Similarly, negative distance from average (NDA) solution is calculated using equation (11) and (12). Then weighted sum of PDA and NDA are obtained using equation (13) and (14) respectively.

TABLE 6 shows weighted PDA values and TABLE 7 shows weighted NDA values. Then normalisation of weighted values calculated using equation (15) and (16) respectively. Appraisal scores are obtained using equation (17). Alternatives then ranked in descending order based on appraisal score. Normalised values of PDA and NDA, appraisal scores and ranking of alternatives are shown in TABLE 8.

D. CODAS Method

Normalized values for CODAS are computed using equation (18). Then weighted normalized values are obtained using equation (19). Based on weighted normalized decision matrix values, negative ideal solution (NIS) for each criterion is determined.

TABLE 9 represents negative ideal solution.

TABLE 10 shows Euclidean and Taxicab distances. Euclidean distances (E_i) and Taxicab distances (T_i) of alternatives are calculated using equation (21) and (22) respectively.

The relative assessment matrix (Ra) and assessment score (Hi) is obtained as defined in step 6 to step 7, using equation (23) and (25) respectively. Obtained results are shown in TABLE 11. Here value of τ is taken as 0.02. Finally, ranking of alternatives based on assessment score is also shown in TABLE 11.

TABLE 2 VIKOR - CALCULATED DATA AND RANKING

CNC Machine Tool	Ei	Fi	Pi	Rank
CMT1	0.3404	0.2887	0.4747	2
CMT2	0.5078	0.2359	0.5707	4
CMT3	0.2222	0.1007	0	1
CMT4	0.5206	0.1762	0.4775	3
CMT5	0.6596	0.3775	1	5

TABLE 3 WASPAS - NORMALISED DECISION MATRIX

CNC Machine Tool	P	OE	C	SS	D	FS
CMT1	1	0.4497	1	1	0.5932	1
CMT2	0.6818	0.5503	0.9	0.7	0.7203	0.9732
CMT3	0.7895	1	0.6429	1	0.7119	0.9254
CMT4	0.6818	0.7919	0.4891	0.7	0.8475	0.7198
CMT5	0.5	1	0.4615	0.4	1	0.6701

TABLE 4 ADDITIVE AND MULTIPLICATIVE IMPORTANCE, JOINT GENERALIZED CRITERION VALUE AND RANKING

CNC Machine Tool	$Q_i^{(1)}$	$Q_i^{(2)}$	Q_i	Rank
CMT1	0.8201	0.7728	0.7965	2
CMT2	0.6925	0.6819	0.6872	4
CMT3	0.8433	0.8324	0.8378	1
CMT4	0.6923	0.6834	0.6878	3
CMT5	0.6600	0.6179	0.6390	5

TABLE 5 EDAS - AVERAGE SOLUTION

Attributes	P	OE	C	SS	D	FS
AV_j	21.6	0.565	7.09	3800	457	5.5873

TABLE 6 WEIGHTED PDA VALUES AND SUM

CMT Machine Tool	P	OE	C	SS	D	FS	SP_i
CMT1	0.1153	0	0.0616	0.0269	0	0.0047	0.2085
CMT2	0	0	0.0497	0	0	0.0040	0.0537
CMT3	0.0454	0.0920	0.0021	0.0269	0	0.0028	0.1692
CMT4	0	0.0128	0	0	0.0049	0	0.0176
CMT5	0	0.0920	0	0	0.0151	0	0.1070

TABLE 7 WEIGHTED NDA VALUES AND SUM

CMT Machine Tool	P	OE	C	SS	D	FS	SN_i
CMT1	0	0.1175	0	0	0.0121	0	0.1296
CMT2	0.0070	0.0792	0	0.0067	0.0036	0	0.0965
CMT3	0	0	0	0	0.0042	0	0.0042
CMT4	0.0070	0	0.0502	0.0067	0	0.0045	0.0684
CMT5	0.1468	0	0.0632	0.0404	0	0.0070	0.2574

TABLE 8 NORMALISED VALUES, APPRAISAL SCORE AND RANKING OF ALTERNATIVES

CNC Machine Tool	NSP_i	NSN_i	ASi	Rank
CMT1	1	0.4964	0.7482	2
CMT2	0.2577	0.6249	0.4413	3
CMT3	0.8116	0.9837	0.8976	1
CMT4	0.0846	0.7342	0.4094	4
CMT5	0.5132	0	0.2566	5

TABLE 9 CODAS - WEIGHTED NORMALISED VALUES AND NEGATIVE IDEAL SOLUTION

CNC Machine Tool	P	OE	C	SS	D	FS
CMT1	0.3775	0.1298	0.1686	0.0852	0.0307	0.0284
CMT2	0.2574	0.1589	0.1517	0.0596	0.0373	0.0276
CMT3	0.2980	0.2887	0.1084	0.0852	0.0368	0.0262
CMT4	0.2574	0.2286	0.0825	0.0596	0.0438	0.0204
CMT5	0.1887	0.2887	0.0778	0.0341	0.0517	0.0190
Negative Ideal Solution	0.1887	0.1298	0.0778	0.0341	0.0307	0.0190

TABLE 10 EUCLIDEAN AND TAXICAB DISTANCES

CNC Machine Tool	Ei	Ti
CMT1	0.2158	0.3400
CMT2	0.1086	0.2123
CMT3	0.2020	0.3632
CMT4	0.1238	0.2122
CMT5	0.1602	0.1799

TABLE 11 RELATIVE ASSESSMENT MATRIX, ASSESSMENT SCORE AND RANKING OF ALTERNATIVES

CNC Machine Tool	CMT1	CMT2	CMT3	CMT4	CMT5	Hi	RANK
CMT1	0	0.2349	0.0138	0.2198	0.2156	0.6840	2
CMT2	-0.2348	0	-0.2443	-0.0152	-0.0192	-0.5136	5
CMT3	-0.0137	0.2443	0	0.2292	0.2251	0.6849	1
CMT4	-0.2197	0.0152	-0.2292	0	-0.0042	-0.4380	4
CMT5	-0.2156	0.0192	-0.2251	0.0041	0	-0.4173	3

TABLE 12 RANKINGS COMPARISON

Rank	VIKOR	WASPAS	EDAS	CODAS	TOPSIS	M-TOPSIS
1	CMT3	CMT3	CMT3	CMT3	CMT3	CMT3
2	CMT1	CMT1	CMT1	CMT1	CMT1	CMT1
3	CMT4	CMT4	CMT2	CMT5	CMT4	CMT2
4	CMT2	CMT2	CMT4	CMT4	CMT2	CMT4
5	CMT5	CMT5	CMT5	CMT2	CMT5	CMT5

TABLE 13 SPEARMAN RANK CORRELATION COEFFICIENT BETWEEN METHODS

Method	VIKOR	WASPAS	EDAS	CODAS	TOPSIS	M-TOPSIS
VIKOR	1	1	0.9	0.7	1	0.9
WASPAS		1	0.9	0.6	1	0.9
EDAS			1	0.6	0.9	1
CODAS				1	0.7	0.6
TOPSIS					1	0.9
M-TOPSIS						1

V. RANKING COMPARISON

TABLE 12 shows the ranking performance of selected multiple criteria decision making methods. We have also applied TOPSIS and Modified TOPSIS methods for this problem in order to check ranking performance. Obtained ranking results of VIKOR, WASPAS, EDAS and CODAS were compared with that of TOPSIS and Modified TOPSIS methods. Table shows that all methods give quite similar results. Spearman`s rank correlation coefficient method is used to compared ranking results. Spearman`s rank correlation test results are shown in

TABLE 13. Spearman`s rank coefficient ranges from -1 to +1. It clear that VIKOR, WASPAS and TOPSIS gives exactly same results. Also, EDAS and M-TOPSIS results are similar. Some methods have coefficient value as 0.6, which is less but still they have close relation between results.

VI. RESULT AND CONCLUSION

This paper studies the ranking performance of four multi criteria decision making techniques for CNC machine tool selection problem. VIKOR, WASPAS, EDAS and CODAS are selected for the analysis. Five CNC machine tool alternatives are evaluated against six CNC machine tool attributes. TABLE 12 shows final ranking of CNC machine tools according to all four methods. CMT3 is the best choice according to all methods. CMT1 is the second-best choice. After first two alternatives, we can see some discrepancies for the remaining positions. These minor discrepancies are due to different mathematical approach used in these methods. Obtained results are very much similar to the results obtained using Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Modified TOPSIS methods. Based on obtained results, we can say that WASPAS, EDAS and CODAS, these latest MCDM techniques are suitable for analysing CNC machine tools. Among all methods, WASPAS is very quick and simple method in terms of calculation, as compare to other three methods. Spearman`s rank correlation coefficient method indicated positive correlation between ranking performances of methods. This proposed model can be extended by combining fuzzy system with these traditional methods. Sensitivity analysis can be conducted to check robustness of methods.

REFERENCES

[1] R. V. Rao, 2007, *Decision Making in the Manufacturing Environment using Graph Theory and Fuzzy Multiple Attribute Decision Making,* 1st ed., London: Springer-Verlag, 2017.

[2] A. Alinezhad, J. Khalili, *New Methods and Applications in Multiple Attribute Decision Making (MADM),* ser. International Series in Operation Research and Management Sciences, Springer, 2019, vol. 277.

[3] S. Önüt, S. S. Kara and T. Efendigil, "A hybrid fuzzy MCDM approach to machine tool selection", *J Intell Manuf,* vol. 19, pp. 443–453, Mar. 2008, https://doi.org/10.1007/s10845-008-0095-3.

[4] S. Chakraborty and E. K. Zavadskas, *"Applications of WASPAS method in Manufacturing Decision Making", Informatica,* vol. 25, pp. 1-20, Jan. 2014.

[5] M. K. Ghorabaee, E. K. Zavadskas, L. Olfat and Z. Turkis, *"Multi-Criteria Inventory Classification Using a New Method of Evaluation Based on Distance from Average Solution (EDAS)", Informatica,* vol. 26, pp. 435-451, Jan. 2015.

[6] S. Chakraborty, E. K. Zavadskas and J. Antucheviciene, *"Application of WASPAS method as a multi-criteria decision-making tool", Economic computation and economic cybernetic studies and research,* vol. 49, pp. 5-22, Jan. 2015.

[7] S. Chakraborty, O. Bhattacharyya, E. K. Zavadskas and J. Antucheviciene, *"Application of WASPAS Method as an Optimization Tool in Non-traditional Machining Processes", Information Technology and Control,* vol. 44, Mar. 2015.

[8] K. Prasad and S. Chakraborty, *"Development of a QFD-based expert system for CNC turning centre selection", J Ind Eng Int,* vol. 11, pp. 575-594, Oct. 2015.

[9] J. Kumar, T. Soota and G. S. Singh, *"TOPSIS and VIKOR approaches to machine tool selection", J. Sci. Res. Adv.,* vol. 2, pp. 125-130, 2015.

[10] M. Yazdani, S. H. Zolfani and E. K. Zavadskas, *"New integration of MCDM methods and QFD in the selection of green suppliers", Journal of Business Economics and Management,* vol. 17, pp. 1097-1113, 2016.

[11] M. Madic, J. Antucheviciene, M. Radovanovic and D. Petkovic, *"Determination of Manufacturing Process Conditions by Using MCDM Methods: Application in Laser Cutting, Economics of Engineering Decisions,* vol. 27, pp. 144-150, March 2016.

[12] M. K. Ghorabaee, E. K. Zavadskas, Z. Turskis and J. Antucheviciene, *"A new combinative distance-based assessment (CODAS) method for multi-criteria decision-making", Economic Computation and Economic Cybernetics Studies and Research,* vol. 50, pp. 25-44, Sept. 2016.

[13] P. Venkateswarlu and B. D. Sarma, *"Selection of equipment by using Saw and Vikor methods", Int. Journal of Engineering Research and Application,* vol. 6, pp. 61-68, Nov. 2016.

[14] D. Panchal, P. Chatterjee, R. K. Shukla T. Choudhury and J. Tamosaitiene, *"Integrated Fuzzy AHP-Codas Framework for Maintenance Decision in Urea Fertilizer Industry", Economic Computation and Economic Cybernetics Studies and Research,* vol. 51, pp. 179-196, 2017.

[15] M. Mathew and S. Sahu, *"Comparison of new multi-criteria decision making methods for material handling equipment selection", Management Science Letters,* vol. 8, pp. 139-150, 2018.

[16] B. Sennaroglu, G. V. Celebi, *"A military airport location selection by AHP integrated PROMETHEE and VIKOR methods", Transportation Research Part D: Transport and Environment",* vol. 59, pp. 160-173, Mar. 2018.

[17] H. Gupta, *"Evaluating service quality of airline industry using hybrid best worst method and VIKOR", Journal of Air Transport Management,* vol. 68, pp. 35-47, May 2018.

[18] M. Yazdani, *"New approach to select materials using MADM tools", Int. J. Business and Systems Research,* vol. 12, pp. 25–42, 2018.

[19] P. Sahoo, M. P. Satpathy, V. K. Singh and A. Bandyopadhyay, *"Performance evaluation in CNC turning of AA6063-T6 alloy using WASPAS approach", World Journal of Engineering,* vol. 15, pp. 700-709, Dec. 2018.

[20] Nilsen Kundakcı, *"An integrated method using MACBETH and EDAS methods for evaluating steam boiler alternatives", J Multi-Crit Decis Anal.,* pp. 1-8, Dec. 2018.

[21] D. Karabasevic, E.K. Zavadskas, D. Stanujkic, G. Popovic and M. Brzakovic, *"An Approach to Personnel Selection in the IT Industry Based on the EDAS Method", Transformations in Business & Economics,* vol. 17, pp. 54-65, 2018.

[22] I. A. Badi, A. M. Abdulshahed and A. G. Shetwan, *"A case study of supplier selection for a steelmaking company in Libya by using the combinative distance-based assessment (CODAS) model", Decision making: Application in management and Engineering,* vol. 1, pp. 1-12, Mar. 2018.

[23] I. Emovon, R. A. Norman, A. J. Murphy and M. O. Okwu, *"Application of WASPAS in enhancing reliability centered maintenance for ship system maintenance", Journal of Engineering and Technology,* vol. 9, 2018.

[24] I. Badi, M. Ballem and A. Shetwan, *"Site selection of Desalination plant in Libya by using Combinative Distance-Based Assessment (CODAS) method", International Journal for Quality Research,* vol. 12, pp. 609-624, 2018.

[25] F. Ecer, *"Third-party logistics (3PLs) provider selection via Fuzzy AHP and EDAS integrated model", Technological and Economic Development of Economy,* vol. 24, pp. 615-634, 2018.

[26] A. S. Sudha, *"Application of EDAS method on Water Requirement in Agriculture", International journal of Engineering and Technology,* vol. 8, pp. 558-561, 2019.

[27] D. Schitea, M. Deveci, M. Iordache, K. Bilgili, I. Akyurt and I. Iordache, *"Hydrogen mobility roll-up site selection using intuitionistic fuzzy sets based WASPAS, COPRAS and EDAS", International Journal of Hydrogen Energy,* vol. 44, pp. 8585-8600, Mar. 2019.

[28] A. I. Maghsoodi, A. I. Maghsoodi, P. Poursoltan, J. Antucheviciene and Z. Turskis, *"Dam construction material selection by implementing the integrated SWARA–CODAS approach with target-based attributes", Archives of Civil and Mechanical Engineering,* vol. 19, pp. 1194-1210, Aug. 2019.

[29] M. Moradian, V. Modanloo and S. Aghaiee, *"Comparative analysis of multi criterial decision making techniques for material selection of brake booster valve body", Journal of Traffic and Transportation Engineering,* vol. 6, pp. 526-534, Oct. 2019.

[30] V. R. Pathapalli, V. R. Basam, S. K. Gudimetta, M. R. Koppula, *"Optimization of machining parameters using WASPAS and MOORA", World Journal of Engineering,* vol. 17, pp. 237–246, 2020.

[31] B. M. Reddy and P. Anand, "EDM of Aluminium Metal Matrix Nano Composite (AL 5056/CNT) and Optimization of its Process Parameters Using WASPAS-S/N Ratio Analysis", International Journal of Mechanical and Production Engineering Research and Development, vol. 10, pp. 249-258, Feb 2020.

[32] R. K. Singh, S. Modgil, *"Supplier selection using SWARA and WASPAS – a case study of Indian cement industry", Measuring Business Excellence,* Vol. 24, pp. 243-265, Mar. 2020.

[33] A. M. Ghaleb, H. Kaid, A. Alsamhan, S. H. Mian and L. Hidri, *"Assessment and Comparison of various MCDM approaches in the Selection of Manufacturing Process", Advances in Materials Science and Engineering,* vol. 2020, Apr. 2020, https://doi.org/10.1155/2020/4039253

[34] A. Narad and M. Joshi, *"Selection of Optimum Fuel Blend using AHP and EDAS Analysis", International Journal of Advanced Research in Engineering and Technology,* vol. 11, pp. 591-601, Sept. 2020.

[35] A. Roy, P. Chatterjee, S. Chakraborty and S. Mondal, *"An Integrated Entropy-Combinative Distance-Based Assessment (CODAS) Method for Aerospace Material Selection", in Proc. of the National Conference on Advanced Materials, Manufacturing and Metrology, At: CSIR-CMERI, Durgapur, West Bengal India,* Feb. 16-17, 2018.

[36] A. Jayant and S. Singh, *"An integrated approach with MOORA, SWARA and WASPAS methods for selection of 3PLSP",* in *Proc. of the International Conference on Industrial Engineering and Operations Management Paris, France,* July 26-27, 2018.