APPLICATION OF EDAS, MARCOS, TOPSIS, MOORA AND PIV METHODS FOR MULTI-CRITERIA DECISION MAKING IN MILLING PROCESS

DO Duc Trung¹

¹Faculty of mechanical engineering, Hanoi University of Industry, Hanoi-100000, Vietnam,
e-mail: doductrung@hau.edu.vn

Abstract: Low surface roughness and high Material Removal Rate (*MRR*) are expected in most machining methods in general and milling method in particular. However, they sometimes do not occur, for example, the *MRR* is often small as the surface roughness is low. In this case, the decisions made should ensure that desires are simultaneously satisfied. This situation leads to a problem known as multi-criteria decision making (*MCDM*). In this study, five methods including *EDAS*, *MARCOS*, *PIV*, *MOORA* and *TOPSIS* are used together for the decision-making in the milling process. The purpose of the research is to determine the value of cutting parameters for both the low surface roughness and large *MRR*. The comparison of these methods for finding the best is carefully discussed as well.

KEYWORDS: EDAS, MARCOS, PIV, MOORA, TOPSIS

Abbreviations

MCDM: Multi-Criteria Decision Making

MRR: Material Removal Rate

SAW: Simple additive weighting.

WASPAS: Weighted aggregates sum product assessment.

TOPSIS: Technique for Order of Preference by Similarity to Ideal Solution

VIKOR: Vlsekriterijumska optimizacija i kompromisno resenje in Serbian.

MOORA: Multiobjective optimization on the basis of ratio analysis.

COPRAS: Complex proportional assessment.

PIV: Proximity indexed value.

PSI: Preference selection index.

EDAS: Evaluation based on distance from average solution

MARCOS: Measurement alternatives and ranking according to compromise solution

CODAS: Combinative distance based assessment

WASPAS: Weighted Aggregated Sum Product Assessment

WPAS: Weighted Product Assessment

1 Introduction

Milling is considered to be the most productive of machining methods, especially in the case of using a face milling cutter where its teeth are involved in the cutting process [1]. This method is commonly used for machining mechanical products, hence, research of seeking solutions in order to improve the quality of machined surface and machining efficiency is increasingly paid attention. One of the research directions primarily concerned is finding a solution to reach the low surface roughness and large *MRR*. Surface roughness directly affects workability and service life of the product, and *MRR* is the most important measure to evaluate the productivity of the machining process [2]. In fact, however, these requirements are sometimes not achieved simultaneously [3]. Several studies also point that out. In an experiment including nine trials of milling Ti-6Al-4V alloy, the trial with the highest *MRR* had the highest surface roughness [4]. The results of twenty-seven SCM440 steel milling experiments show that the lowest surface roughness and *MRR* were in the same test [5]. As nine 060A4 steel milling tests were performed, the one with the lowest surface roughness also had the small *MRR* [6]. Upon implementing twenty experiments for milling SKD11 steel, the test with the lowest surface roughness nearly had the minimum *MRR* [7], etc. Under these circumstances, it is necessary to define an experiment where the surface roughness is considered "minimum" and the *MRR* is considered "maximum". This is called "multi-criteria decision making" [4-7].

Evaluation based on Distance from Average Solution (*EDAS*) is a multi-criteria decision making method introduced for the first time in 2015 [8]. It has been applied in several studies. The *EDAS* method was applied to multi-criteria decision making for robot selection by considering four parameters including: load capacity, repeatability error, vertical reach, and degrees of freedom [9,10]. The *EDAS* method was also applied to multi-criteria decision making for material handling equipment [10]. Besides the *EDAS*, authors of these papers used four other methods (including *CODAS*, *MOORA*, *WASPAS* and *TOPSIS*) to solve the same problem. The results demonstrated that all five methods identified the best solution. The multi-criteria decision-making for choosing a green supplier to obtain objectives given by taking account of four factors including cost, quality, environment and delivery time was also carried out using the *EDAS* [12]. Some researchers [13] applied the *EDAS* to make a decision about selecting a smartphone that meets the criteria of cost and necessary features for users' needs. The *EDAS* was also used [14] to make multi-criteria decisions for seeking a diesel engine. Besides the method, authors also applied five other methods (including *MOORA*, *WSPAS*, *TOPSIS*, *WASPAS*, and *VIKOR*) to select a best alternative. The results revealed that: except for the *TOPSIS* method, the other five (including *EDAS*, *MOORA*, *WPAS*, *WASPAS*, and *VIKOR*) all pointed out the same best solution. The *EDAS* is also used to decide the percentage of additives in the process of making composite materials (Titanium Di-Oxide Filled Woven Glass Fibre Reinforced Polymer Composites). The purpose of this study is to make a composite material that simultaneously obtains the desired tensile strength, compressive strength, adhesion strength and impact strength [15]. The *EDAS* method was applied to rank in the insurance industry of twenty-seven OECD countries (Organization for Economic Cooperation and Development) [16]. The use of *EDAS* method was effective to provide solutions for reducing carbon emissions into the environment [17], choosing the type of wireless sensor network [18], and selecting sewing machines for the textile factory [19]; etc.

It can be seen that the *EDAS* method is used to make multi-criteria decisions in different fields. However, there is likely no application of the *EDAS* method for multi-criteria-decision making in the machining process in general and milling process in particular.

Measurement Alternatives and Ranking according to Compromise Solution (*MARCOS*) is another multi-criteria decision making method introduced for the first time in 2020 [20]. Although it has only been published for a short time, this method has been applied to multi-criteria decision making in a number of studies such as: determining intermediate modes of transport between countries in the Danube region [21], reducing risks in road traffic [22], choosing cargo handling equipment for small warehouses [23], recruiting employees for a transportation company [24], identifying construction cost [25]. However, it appears that there are no studies on application of the *MARCOS* method to multi-criteria decision making in the machining process in general and milling process in particular.

Among the multi-criteria decision-making methods, *TOPSIS* is the most used method in many different fields [13, 26]. In a recent study, eight multi-criteria decision-making methods were compared for 150Cr14 steel turning operation [27]. Its researchers used eight methods at the same time, including *SAW*, *WASPAS*, *TOPSIS*, *VIKOR*, *MOORA*, *COPRAS*, *PIV*, and *PSI*. The study concluded that seven of the methods identified the same solution (with the exception of the *PSI* method). However, during making a multi-criteria decision on the steel machining process of ASTM A588, it was shown that the *TOPSIS* method did not determine the best option compared to the *MOORA* method [28], and in the process of making a multi-criteria decision on the 9XC steel machining operation, it was also revealed that the *TOPSIS* method did not define the best alternative compared to *PIV* [29]. Thus, even though the *TOPSIS* is mostly used, there are probably other methods to be more effective than it under certain circumstances.

In this study, a multi-criteria decision on the milling process is made using all the five methods, including *EDAS*, *MARCOS*, *PIV*, *MOORA* và *TOPSIS*. There are two reasons for this choice: *First*, as mentioned, the *EDAS* and *MARCOS* are applied for multi-criteria decision making in various fields, but neither of them has ever been used for multi-criteria decision-making of the milling process; *Second*, *TOPSIS* is the most used method in multi-criteria decision making, but some studies indicated the *PIV* and *MOORA* are more effective than the *TOPSIS*. Consequently, all five methods may provide a useful comparison.

2 Several methods of multi-criteria decision making

2.1 *EDAS method*

The steps for implementation of multi-criteria decision making according to the *EDAS* method are as follows [8].

Step 1: Building a decision matrix based on the following formula:

$$X = [x_{ij}]_{m \times n} = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ x_{21} & \cdots & x_{2n} \\ \vdots & \cdots & \vdots \\ x_{mn} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

Where: m is the number of options, n is the number of criteria, x_{ij} is the value of criterion j at option i .

Step 2: Determining an average (AVG) of the options.

$$AVG = \frac{\sum_{i=1}^m x_i}{m} \quad (2)$$

Step 3: Defining positive distance (*PD*) and negative distances (*ND*) from an average

$$PD_{ij} = \frac{\max[0, (x_{ij} - AVG_j)]}{AVG_j} \quad \text{if } j \text{ is an indicator whose value is as high as possible} \quad (3)$$

$$PD_{ij} = \frac{\max[0, (AVG_j - x_{ij})]}{AVG_j} \quad \text{if } j \text{ is an indicator whose value is as low as possible} \quad (4)$$

$$ND_{ij} = \frac{\max[0, (AVG_j - x_{ij})]}{AVG_j} \quad \text{if } j \text{ is an indicator whose value is as high as possible} \quad (5)$$

$$ND_{ij} = \frac{\max[0, (x_{ij} - AVG_j)]}{AVG_j} \quad \text{if } j \text{ is an indicator whose value is as low as possible} \quad (6)$$

Step 4: Calculating the sum of positive distances (SoP) and the sum of negative distances (SoN).

$$SoP_i = \sum_{j=1}^m w_j \cdot PD_{ij} \quad (7)$$

$$SoN_i = \sum_{j=1}^m w_j \cdot ND_{ij} \quad (8)$$

where w_j is the weight of the criterion j .

Step 5: Normalizing the SoP and SoN values according to the formula.

$$SSoP_i = \frac{SoP_i}{\max(SoP_i)} \quad (9)$$

$$SSoN_i = 1 - \frac{SoN_i}{\max(SoN_i)} \quad (10)$$

Step 6: Calculating appraisalment score (APS) of the options based on the formula.

$$APS_i = \frac{1}{2} (SSoP_i + SSoN_i) \quad (11)$$

Step 7: Ranking the options according to the rule that the option with the highest APS_i is considered the best.

2.2 MARCOS method

The steps for implementation of multi-criteria decision making according to the *MARCOS* method are as follows [20]:

Step 1: Similar to step 1 of the EDAS method.

Step 2: Building an expanded matrix by adding an ideal solution (AI) and the opposite solution to the ideal solution (AAI).

$$X = \begin{matrix} & AAI & \begin{bmatrix} x_{aa1} & \cdots & x_{aan} \\ A_1 & x_{11} & \cdots & x_{1n} \\ A_2 & x_{21} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ A_m & x_{m1} & \cdots & x_{mn} \\ AI & x_{ai1} & \cdots & x_{ain} \end{bmatrix} \end{matrix} \quad (12)$$

where:

$AAI = \min(x_{ij}); i = 1, 2, \dots, m; j = 1, 2, \dots, n$ if j is an indicator whose value is as high as possible

$AAI = \max (x_{ij}); i = 1, 2, \dots, m; j = 1, 2, \dots, n$ if j is an indicator whose value is as low as possible

$AI = \max (x_{ij}); i = 1, 2, \dots, m; j = 1, 2, \dots, n$ if j is an indicator whose value is as high as possible

$AI = \min (x_{ij}); i = 1, 2, \dots, m; j = 1, 2, \dots, n$ if j is an indicator whose value is as low as possible

Step 3: Normalizing the expanded matrix according to the formula:

$$n_{ij} = \frac{x_{AI}}{x_{ij}} \quad \text{if } j \text{ is an indicator whose value is as low as possible} \quad (13)$$

$$n_{ij} = \frac{x_{ij}}{x_{AI}} \quad \text{if } j \text{ is an indicator whose value is as high as possible} \quad (14)$$

Step 4: Building a normalized matrix taking into account the weights of the parameters with the normalized value calculated according to the formula.

$$v_{ij} = n_{ij} \cdot w_j \quad (15)$$

where, w_j is the weight of the criterion j .

Step 5: Calculating the coefficients K_i^+ and K_i^- according to the formula:

$$K_i^- = \frac{S_i}{S_{AAI}} \quad (16)$$

$$K_i^+ = \frac{S_i}{S_{AI}} \quad (17)$$

where:

S_i , S_{AAI} and S_{AI} are the sum of the values of v_{ij} , x_{aai} and x_{ai} , respectively, where $i = 1, 2, \dots, m$.

Step 6: Calculating $f(K_i^+)$ and $f(K_i^-)$ according to the formula:

$$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-} \quad (18)$$

$$f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-} \quad (19)$$

Step 7: Calculating $f(K_i)$ according to the following formula and rank the options.

$$f(K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1-f(K_i^+)}{f(K_i^+)} + \frac{1-f(K_i^-)}{f(K_i^-)}} \quad (20)$$

Ranking is based on the rule that the option with the highest value of the $f(K_i)$ is considered the best.

2.3 PIV method

The steps for implementation of multi-criteria decision making according to the *PIV* method are as follows [30]:

Step 1: Similar to step 1 of the *EDAS* method.

Step 2: Calculating the conversion values.

$$x'_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^n x_{ij}^2}} \quad (21)$$

Step 3: Calculating the normalized value according to the formula.

$$X = w_j \cdot x'_{ij} \quad (22)$$

where, w_j is the weight of the criterion j .

Step 4: Calculating weighted proximity index

$$u_i = \begin{cases} X_{\max} - X_i & \text{for } C_1, C_2, \dots, C_n \in B \\ X_i - X_{\min} & \text{for } C_1, C_2, \dots, C_n \in C \end{cases} \quad (23)$$

where B represents the criterion whose value is as high as possible, and C represents the criterion whose value is as low as possible.

Step 5: Determining the overall proximity value according to the following formula.

$$d_i = \sum_{j=1}^n u_i \quad (24)$$

Step 6: Ranking the options according to the rule that the option with the highest of d_i is considered the best.

2.4 MOORA method

The steps for implementation of multi-criteria decision making according to the *MOORA* method are as follows [31]:

Step 1: Similar to step 1 of the *EDAS* method.

Step 2: Calculating the normalized decision matrix $[X_{ij}]_{m \times n}$ based on the formula.

$$K = [X_{ij}]_{m \times n} \quad K_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} \quad (25)$$

Step 3: Calculating the decision matrices after normalizing the weights based on the formula.

$$W_{ij} = w_j \times k_{ij} \quad (26)$$

Step 4: Defining P_i and R_i based on the following formulas.

$$P_i = \frac{1}{|B|} \sum_{j \in B} W_{ij} \quad (27)$$

$$R_i = \frac{1}{|NB|} \sum_{j \in NB} W_{ij} \quad (28)$$

where B represents the criterion whose value is as high as possible, and NB represents the criterion whose value is as low as possible.

Step 5: Identifying Q_i based on the following formula.

$$Q_i = P_i - R_i \quad (29)$$

2.5 TOPSIS method

The steps for implementation of multi-criteria decision making according to the *TOPSIS* method are as follows [32]:

Step 1: Similar to step 1 of the *EDAS* method.

Step 2, step 3: Similar to step 2 and 3 of the *MOORA* method.

Step 4: Determining the best solution A^+ and the worst solution A^- for the criteria according to the following formulas.

$$A^+ = \{k_1^+, k_2^+, \dots, k_j^+, \dots, k_n^+\} \quad (30)$$

$$A^- = \{k_1^-, k_2^-, \dots, k_j^-, \dots, k_n^-\} \quad (31)$$

where: k_j^+ and k_j^- are the best and worst values of criterion j , respectively.

Step 5: Identifying S_i^+ and S_i^- based on the following formulas.

$$S_i^+ = \sqrt{\sum_{j=1}^n (k_{ij} - k_j^+)^2} \quad i = 1, 2, \dots, m \quad (32)$$

$$S_i^- = \sqrt{\sum_{j=1}^n (k_{ij} - k_j^-)^2} \quad i = 1, 2, \dots, m \quad (33)$$

Step 6: Defining C_i^* and based on the following formulas.

$$C_i^* = \frac{S_i^-}{S_i^+ + S_i^-} \quad i = 1, 2, \dots, m; 0 \leq C_i^* \leq 1 \quad (34)$$

Step 7: Ranking the options according to the rule that the option with the highest C_i^* is considered the best.

3 Experiment of milling operation

SB410 steel (conforming to JIS - Japanese standard) was used in the experiments. The results of spectral analysis determined the chemical composition of steel as shown in Table 1. This steel has good machinability, low cost and is the most popular steel for manufacturing common mechanic parts made of silver, shafts, gears, levers.

Table 1. Chemical composition of SB410 steel

Composition (%)									
<i>C</i>	<i>Si</i>	<i>Mn</i>	<i>Cr</i>	<i>Ni</i>	<i>Mo</i>	<i>V</i>	<i>Ti</i>	<i>B</i>	<i>Cu</i>
0.44	0.25	0.63	0.24	0.11	0.04	0.02	0.002	0.0006	0.23

A JLVH320B vertical milling machine was used to perform the experiments. Due to the use of a hydraulic motor for controlling feed, feed rate can be adjusted at any level. The determination of the feed rate is made by timing. The cutting tool moves by 0,02 mm for each mark on the vertical vernier of the machine, based on which the depth of cut is adjusted. The control of the spindle speed of the machine is done through the lever system, which includes twenty-four spindle speed levels.

The cutting tool used in this study is made of a hard alloy, coated with TiN. Its type is widely used in milling due to a relatively high heat resistance and good cutting performance [33]. The cutting tool holder has a diameter of 82 mm.

The spindle speed, feed rate and depth of cut are selected as the input parameters for experiments. These three parameters can all be quickly adjusted by the machine operator and are also selected as experimental input parameters in many studies [34]. Their values are chosen based on the author's experience in production during milling SB410 steel as well as in accordance with the ability of the testing machine. The values of cutting parameters are presented in Table 2.

Table 2. Cutting parameters

Parameter	Symbol	Unit	Value at level		
			1	2	3
Spindle speed	n	rev/min	70	105	126
Feed rate	f	mm/min	538	788	1152
Depth of cut	a_p	mm	0.4	0.6	0.8

Taguchi method is applied to design a matrix experiment. This method has more advantages than other experimental matrix design methods, namely: the number of experiments is minimum, the input parameters are possibly both quantitative and qualitative, the values of the input parameters do not need to comply with the rule of average [35, 36]. In this case, for example, the level number of spindle speeds of the milling machine is finite, its value encoded at level 2 which is supposed to be the average of the values encoded at level 1 and 3 (ex: $105 \neq (70+126)/2$) is not appropriate. Hence, the Taguchi is the most suitable to design the experimental matrix. With three input parameters and three values for each of them, the experimental matrix is designed as an orthogonal array, including nine trials as shown in Table 3.

Table 3. Orthogonal array $L9$ and result

No.	Code value			Actual value			Response	
	n	f	a_p	n (rev/min)	f (mm/min)	a_p (mm)	R_a (μm)	MRR (mm^3/min)
A1	1	1	1	538	70	0.4	0.571	1120
A2	1	2	2	538	100	0.6	0.818	2400
A3	1	3	3	538	130	0.8	0.493	4160
A4	2	1	2	788	70	0.6	0.426	1680
A5	2	2	3	788	100	0.8	0.470	3200
A6	2	3	1	788	130	0.4	0.851	2080
A7	3	1	3	1152	70	0.8	0.437	2240
A8	3	2	1	1152	100	0.4	0.694	1600
A9	3	3	2	1152	130	0.6	0.717	3120

In order to reduce random errors during the experiment, the surface roughness was measured at least three times for each specimen, the roughness value at each experiment was the average of measurements. Due to calculation based on formula (35), MRR is not affected by the random errors. Where f , a_p , b_w are feed rate, depth of cut and width of cut, respectively. Since the milling cutter diameter is 82 mm and the width of the workpiece is 40 mm, it is possible to cut the workpiece with one pass. Therefore, the width of cut is equal to the width of the workpiece, $b_w = 40$ mm.

$$MRR = f \cdot a_p \cdot b_w \text{ (mm}^3/\text{min)} \quad (35)$$

The tests were performed in the order shown in Table 3, the surface roughness and MRR were included in this table as well.

In Table 3, the minimum surface roughness is 0.426 (μm) at A4, while the maximum MRR is 4160 (mm^3/min) at A3. Thus, it is clear that there is no solution that has the minimum surface roughness and the maximum MRR simultaneously. It is only possible to define an alternative where the surface roughness is considered to be “lowest” and the MRR is considered to be “highest” if multi-criteria decision making is applied.

4 Multi-criteria decision making

4.1 Determination of the weights for the criteria

In this study, the weights of the criteria were determined by the Entropy weight method. The Entropy method is recommended to use for comparison of multi-criteria decision-making methods [27]. It is introduced in many papers [27, 37]. The weights of surface roughness and *MRR* calculated are 0.6641 and 0.3359, respectively.

4.2 Application of EDAS method

The decision matrix is the last two columns on the right of the experimental result table (table 3).

The average values of surface roughness and *MRR* are correspondingly defined are 0.609 (μm) và 2400 (mm^3/min) based on formula (2).

The PD_{ij} and ND_{ij} values of surface roughness and *MRR* are determined based on formula (3), (4), (5) and (6), as shown in Table 4.

Table 4. PD_{ij} and ND_{ij} of surface roughness and *MRR*

No.	PD_{ij}		ND_{ij}	
	<i>Ra</i>	<i>MRR</i>	<i>Ra</i>	<i>MRR</i>
A1	0.0617	0.0000	0.0000	1.1429
A2	0.0000	0.0000	0.3442	0.0000
A3	0.1899	0.7333	0.0000	0.0000
A4	0.3000	0.0000	0.0000	0.4286
A5	0.2277	0.3333	0.0000	0.0000
A6	0.0000	0.0000	0.3984	0.1538
A7	0.2819	0.0000	0.0000	0.0714
A8	0.0000	0.0000	0.1404	0.5000
A9	0.0000	0.3000	0.1782	0.0000

The value of SoP_i , SoN_i , $SSoP_i$, $SSoN_i$, APS_i as shown in Table 5 is determined by formula (7), (8), (9), (10), (11). The ranking results of the options are also presented in this table.

Table 5. Some parameters in EDAS

No.	SoP_i	SoN_i	$SSoP_i$	$SSoN_i$	APS_i	Rank
A1	0.0410	0.3839	0.1100	0.0000	0.0550	9
A2	0.0000	0.2285	0.0000	0.4047	0.2023	6
A3	0.3724	0.0000	1.0000	1.0000	1.0000	1
A4	0.1992	0.1440	0.5349	0.6250	0.5799	4
A5	0.2632	0.0000	0.7066	1.0000	0.8533	2
A6	0.0000	0.3162	0.0000	0.1763	0.0881	8
A7	0.1872	0.0240	0.5026	0.9375	0.7201	3
A8	0.0000	0.2612	0.0000	0.3196	0.1598	7
A9	0.1008	0.1183	0.2706	0.6918	0.4812	5

4.3 Application of MARCOS method

Formula (12) is applied to identify the AI of surface roughness and MRR correspondingly are 0.426 (μm), 4160 (mm^3/min); AAI of surface roughness and MRR correspondingly are 0.851 (μm), 1120 (mm^3/min).

Formulas (13) to (20) are used to define the parameters of n_{ij} , v_{ij} , K_i^- , K_i^+ , $f(K_i^-)$, $f(K_i^+)$ and $f(K_i)$ as shown in Table 6. The ranking results of the options are also presented in this table.

Table 6. Some parameters in MARCOS

No.	n_{ij}		v_{ij}		K_i^-	K_i^+	$f(K_i)$	Rank
	Ra	MRR	Ra	MRR				
$A1$	0.7461	0.2692	0.4954	0.0904	0.00052	0.00014	0.000133	6
$A2$	0.5208	0.5769	0.3458	0.1938	0.00048	0.00013	0.000123	7
$A3$	0.8641	1.0000	0.5738	0.3359	0.00081	0.00022	0.000207	1
$A4$	1.0000	0.4038	0.6641	0.1357	0.00071	0.00019	0.000182	4
$A5$	0.9064	0.7692	0.6019	0.2584	0.00077	0.00021	0.000196	2
$A6$	0.5006	0.5000	0.3324	0.1680	0.00045	0.00012	0.000114	9
$A7$	0.9748	0.5385	0.6474	0.1809	0.00074	0.00020	0.000188	3
$A8$	0.6138	0.3846	0.4076	0.1292	0.00048	0.00013	0.000122	8
$A9$	0.5941	0.7500	0.3946	0.2519	0.00058	0.00016	0.000147	5

4.4 Application of PIV method

Formulas (21) to (24) are applied to calculate the values in the PIV method, the results are presented in Table 7. The ranking results of the options are also presented in this table.

Table 7. Some parameters in PIV

No.	x'_{ij}		$X = w_j \cdot x'_{ij}$		u_i		d_i	Rank
	Ra	MRR	Ra	MRR	Ra	MRR		
$A1$	0.30299	0.14579	0.2012	0.0490	0.0511	0.1329	0.1840	6
$A2$	0.43406	0.31240	0.2882	0.1049	0.1381	0.0770	0.2151	8
$A3$	0.26160	0.54149	0.1737	0.1819	0.0236	0.0000	0.0236	1
$A4$	0.22605	0.21868	0.1501	0.0735	0.0000	0.1084	0.1084	4
$A5$	0.24940	0.41653	0.1656	0.1399	0.0155	0.0420	0.0575	2
$A6$	0.45157	0.27075	0.2999	0.0910	0.1498	0.0910	0.2407	9
$A7$	0.23189	0.29157	0.1540	0.0979	0.0039	0.0840	0.0878	3
$A8$	0.36826	0.20827	0.2445	0.0700	0.0944	0.1119	0.2064	7
$A9$	0.38046	0.40612	0.2527	0.1364	0.1025	0.0455	0.1480	5

4.5 Application of MOORA method

Formulas (25) to (29) are used to calculate the values in the MOORA method, the results are presented in Table 8. The ranking results of the options are also presented in this table.

Table 8. Some parameters in *MOORA*

No.	K_{ij}		W_{ij}		P_i	R_i	Q_i	Rank
	Ra	MRR	Ra	MRR				
A1	0.3030	0.1458	0.2012	0.0490	0.0490	0.2012	-0.1522	6
A2	0.4341	0.3124	0.2882	0.1049	0.1049	0.2882	-0.1833	8
A3	0.2616	0.5415	0.1737	0.1819	0.1819	0.1737	0.0082	1
A4	0.2261	0.2187	0.1501	0.0735	0.0735	0.1501	-0.0767	4
A5	0.2494	0.4165	0.1656	0.1399	0.1399	0.1656	-0.0257	2
A6	0.4516	0.2707	0.2999	0.0910	0.0910	0.2999	-0.2089	9
A7	0.2319	0.2916	0.1540	0.0979	0.0979	0.1540	-0.0560	3
A8	0.3683	0.2083	0.2445	0.0700	0.0700	0.2445	-0.1746	7
A9	0.3805	0.4061	0.2527	0.1364	0.1364	0.2527	-0.1162	5

4.6 Application of TOPSIS method

Formulas (30) to (34) are applied to define the values in the TOPSIS method, the results are presented in Table 9. The ranking results of the options are included in this table as well.

Table 9. Some parameters in *TOPSIS*

No.	S_i^+	S_i^-	C_i^*	Rank
A1	0.1424	0.0987	0.4093	6
A2	0.1581	0.0572	0.2655	8
A3	0.0236	0.1833	0.8859	1
A4	0.1084	0.1517	0.5832	4
A5	0.0447	0.1622	0.7837	2
A6	0.1752	0.0420	0.1933	9
A7	0.0840	0.1539	0.6468	3
A8	0.1465	0.0592	0.2878	7
A9	0.1122	0.0994	0.4698	5

Summary of ranking results according to different multi-criteria decision-making methods are shown in Table 10.

The data in Table 10 revealed that:

- All five methods found that A3 is the best option. In this case, $MRR = 4160$ (mm³/min) is the maximum value among nine options performed. Although the surface roughness at A3 is not minimum, it is slightly higher than the surface roughness at A4, A5 and A7. As a result, it can be said that A3 is the best option.

- The order of ranking options according to the three methods *PIV*, *MOORA* and *TOPSIS* is the same. This emphasizes that the ranking of options is successful and A3 is really the best option.

- The *EDAS* and *MARCOS* method both identified A3 as the best option (same as the three methods *PIV*, *MOORA* and *TOPSIS*). This also confirms that the application of the two methods *EDAS* and *MARCOS* has been successful in this study.

Table 10. Ranking options based on different methods.

No.	Criteria		Multi-criteria decision-making methods				
	<i>Ra</i>	<i>MRR</i>	<i>EDAS</i>	<i>MARCOS</i>	<i>PIV</i>	<i>MOORA</i>	<i>TOPSIS</i>
A1	0.571	1120	9	6	6	6	6
A2	0.818	2400	6	7	8	8	8
A3	0.493	4160	1	1	1	1	1
A4	0.426	1680	4	4	4	4	4
A5	0.470	3200	2	2	2	2	2
A6	0.851	2080	8	9	9	9	9
A7	0.437	2240	3	3	3	3	3
A8	0.694	1600	7	8	7	7	7
A9	0.717	3120	5	5	5	5	5

- Five out of nine options ranked in the *EDAS* are the same as the three methods *PIV*, *MOORA* and *TOPSIS*. Meanwhile, seven out of nine options ranked in the *MARCOS* are the same as the three methods *PIV*, *MOORA* and *TOPSIS*. Between the two methods *EDAS* and *MARCOS*, five out of nine options ranked are the same. In order to explain the difference in ranking the options, more in-depth studies in the field of mathematics are needed.

- Both the best and worst options defined by the *MARCOS* method are the same as the three methods *PIV*, *MOORA* and *COPRAS*. This is explained by the fact that the *MARCOS* method itself takes into account the ideal solution (*AI*) and the opposite solution to the ideal solution (*AAI*).

- To obtain the "*minimum*" surface roughness and the "*maximum*" *MRR*, the values of the spindle speed, feed rate and depth of cut are 788 (rev/min), 70 (mm/min) and 0.6 (mm), respectively.

CONCLUSION

In this research, the B410 steel milling experiment was conducted according to the matrix designed by the Taguchi method. The spindle speed, feed rate and depth of cut were the input parameters. The surface roughness and *MRR* were identified in each experiment. Five methods *EDAS*, *MARCOS*, *PIV*, *MOORA* and *TOPSIS* were used for multi-criteria decision making so as to have the minimum surface roughness and maximum *MRR* at the same time. Some conclusions are drawn as follows:

- The ranking results of the options based on the three methods *PIV*, *MOORA* and *TOPSIS* are the same.
- All five multi-criteria decision-making methods identify an option that is considered the best among the implemented options.
- For the first time, two methods *EDAS* and *MARCOS* are used for multi-criteria decision-making in the milling process and successful in this study.
- Upon machining with a spindle speed of 788 (rev/min), a feed rate of 70 (mm/min) and a depth of cut of 0.6 (mm), the surface roughness is and the *MRR* is maximum.

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