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Comparison of the *RAFSI* and *PIV* method in multi-criteria decision making: application to turning processes

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Abstract. Multi-criteria decision-making (*MCDM*) methods are used in many fields so as to rank alternatives and find the best one. However, rank reversal after adding or removing an alternative can occur in using some of the methods. In this study, two methods *RAFSI* and *PIV* were compared for application of making multi-criteria decisions. They are known to be capable of avoiding rank reversal problems. Sixteen 9XC steel turning tests were performed for the experiment. Tool holder length, spindle speed, feed rate and depth of cut are parameters that vary in each test. Three criteria for evaluating the turning process consist of *MRR*, *RE* and *Ra*. Four methods including *MEREC, ROC, RS* and *EQUAL* were used for determining weights of the criteria. The blend of two multi-criteria decision making methods (*RAFSI* and *PIV*) with four weight-determining methods resulted in eight ranking options. This is a new approach of the study. A positive outcome was reached that all eight ranking options identified the same best test. The best experiment must ensure to have maximum *MRR* and minimum *RE* and *Ra* simultaneously. A detailed discussion of the ranking results in each case was also carried out. Finally, the directions and issues that need to be studied further were pointed out in this paper as well.

Keywords: *MCDM* / *RAFSI* / *PIV* / Weight / turning

1 Introduction

In many fields as well as business activities, it is desirable in all cases to find solutions for simultaneously achieving goals of the criteria. In fact, however, this expectation is probably difficult to obtain. For example, in mechanical processing, high machining accuracy leads to low machining productivity and vice versa [1]. In this case, it is necessary to have solutions to ensure that criteria are simultaneously satisfied. For example, in the process of mechanical operation, it is needed to define a solution for having the highest machining accuracy and the highest machining productivity at the same time. The application of multi-criteria decision-making methods is a fairly common approach so as to solve this problem at the moment.

Recently, there are many multi-criteria decision-making methods proposed by scholars, such as: *TOPSIS*, *MOORA*, *COPRAS*, *WASPAS*, *VIKOR*, *PSI*, *RIM*, etc., and they are applied in many different fields. However, the disadvantage of these methods in use is that they are able to create the rank reversal since alternatives are added or removed [2,3].

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RAFSI was presented in 2020 and is known as a multi-criteria decision making method capable of lessening ranking changes [2]. Several studies were constructed, applying this approach to: selection of construction machinery [4], selection of strategies for healthcare systems development in emergency situations caused by the Covid-19 pandemic [5], selection of a location for emergency medical services [6].

PIV was introduced in 2018 and is known as a multi-criteria decision making method capable of limiting ranking changes as well [3]. It was applied in some studies in order to: select an e-learning site [7]; chose materials for manufacturing some auto parts [8]; define elements of transporting-goods activities between countries in the *EU* [9]; choose additives for a production process [10]; select cutting tool material, tool nose radius, spindle speed, feed rate and depth of cut for obtaining the maximum *MRR* and minimum surface roughness when milling SCM440 steel [11]; identify the city to establish a textile company in Turkey [12].

A number of studies comparing the *PIV* with other methods was also implemented. The *PIV* and *TOPSIS* method were considered in the decision-making process of turning 9XC steel [13]. This study indicated that the *PIV* method is more effective than the *TOPSIS* method in determining the best alternative. The *PIV* and *WASPAS* methods were applied in order to make multi-criteria decisions on the external cylindrical grinding process of 65G steel [14]. This research stated that the *PIV* and *WASPAS* method identified the same best alternative. The *PIV* and *EDAS*, *TOPSIS*, *MARCOS*, *MOORA* methods were used for multi-criteria decision making of the SB410 steel milling process [15]. This study revealed that all five methods used defined the same best experiment. The *PIV* and *SAW*, *WASPAS*, *TOPSIS*, *VIKOR*, *MOORA*, *COPRAS*, *PSI* methods were applied in order to make a multi-criteria decision on turning operation of 150Cr14 steel [16]. This paper demonstrated that the *PIV* method with the *SAW, WASPAS, TOPSIS, VIKOR, MOORA, COPRAS* methods all found the best alternative, and they are also more effective than the *PSI* method.

In summary, the accuracy of the *PIV* method in multi-criteria decision making is confirmed through some of the studies. Since *PIV* and *RAFSI* are both known as multi-criteria decision making methods capable of dealing with the rank reversal problems, a comparison of the two methods has not been conducted to date. For this reason, this research is aiming to fill that gap.

Upon making a multi-criteria decision on the basis of the *RAFSI*, *PIV* or most other methods (except for some methods such as *PSI*, *PEG*), the weights for the criteria must be determined. However, the weights of the criteria identified by the different methods lead to differences in ranking the criteria [17]. Consequently, in order to compare two multi-criteria decision-making methods, several methods of defining the weights should be used simultaneously.

MEREC is a weighting method that was introduced in 2021 [18]. Several studies on multi-criteria decision-making applied it to determine the weights of criteria to: determine locations to place distribution centers in logistics operations [19]; classify documents [20]. In a recent study on making multi-criteria decisions during the turning process under four methods: *MAIRCA, EAMR, MARCOS* and *TOPSIS* were also recommended that *MEREC* should be used to define the weights of the criteria for comparing the methods of multi-criteria decision making [21].

As mentioned, however, so as to compare multi-criteria decision-making methods, it is needed to consider multiple weighting methods at the same time. In this study, *ROC*, *RS* and *EQUAL* methods are also used apart from the *MEREC* method, since determining the weights based on these methods is fairly simple, with only a formula in each one. Details of applying them are presented in the next section of this research.

This study compares the *RAFSI* and *PIV* method in making multi-criteria decisions. Four methods: *MEREC, ROC, RS* and *EQUAL* were applied simultaneously to determine the weights of the criteria. Making multi-criteria decisions for a turning process is used to compare the two methods *RAFSI* and *PIV*.

2 Multi criteria decision-making methods

2.1 RAFSI method

The steps for implementation of multi-criteria decision making according to the *RAFSI* method are as follows [2]:

Step 1: Build a decision matrix.

$$Y = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ y_{m1} & y_{m2} & \cdots & y_{mn} \end{bmatrix}, \quad (1)$$

where: m is the number of alternatives; n is the number of criteria; $i = 1,..., m$; $j = 1,..., n$.

Step 2: Determine ideal values (*AI*) and anti-ideal values (*AAI*) for each criterion.

– For min criteria: the ideal values must be less than the minimum and the anti-ideal values must be greater than the maximum. That means:

$$y_{AI} < \min y_i, \quad (2)$$

$$y_{AAI} > \max y_i, \quad (3)$$

– For max criteria: the ideal values must be greater than the maximum and the anti-ideal values must be less than the minimum. That means:

$$y_{AI} > \max y_i, \quad (4)$$

$$y_{AAI} < \min y_i, \quad (5)$$

Step 3: Define a function for mapping the criteria, based on the formula.

$$s_j = f_j(y) = \frac{m-1}{y_{AI} - y_{AAI}} y_j + \frac{y_{AI} - m \cdot y_{AAI}}{y_{AI} - y_{AAI}}. \quad (6)$$

Step 4: Build standardized matrix.

$$S = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1n} \\ s_{21} & s_{22} & \cdots & s_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ s_{m1} & s_{m2} & \cdots & s_{mn} \end{bmatrix}. \quad (7)$$

Step 5: Calculate arithmetic (*A*) and harmonic (*H*) means.

$$A = \frac{1+m}{2}, \quad (8)$$

$$H = \frac{1}{1+\frac{1}{m}}. \quad (9)$$

Step 6: Form normalized decision matrix.

$$T = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} t_{11} & t_{12} & \cdots & t_{1n} \\ t_{21} & t_{22} & \cdots & t_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ t_{m1} & t_{m2} & \cdots & t_{mn} \end{bmatrix}, \quad (10)$$

where:

– For max criteria:

$$t_{ij} = \frac{s_{ij}}{2A}, \tag{11}$$

– For min criteria:

$$t_{ij} = \frac{H}{2s_{ij}}. \tag{12}$$

Step 7: Calculate criteria functions of the alternatives *V(Ai)* based on the following formula.

$$V(A_i) = \sum_{j=1}^{n} w_j \cdot t_{ij}. \tag{13}$$

where w_j is the weight of the criterion j.

Step 8: Rank the alternatives according to the rule that the alternative with the highest $V(A_i)$ is considered the best.

2.2 PIV method

The experimental matrix was also built as in (1). The steps for implementation of multi-criteria decision making according to the *PIV* method are as follows [3]:

Step 1: Identify the conversion values.

$$y'_{ij} = \frac{y_{ij}}{\sqrt{\sum_{i=1}^{n} y_{ij}^2}}. \tag{14}$$

Step 2: Define normalized values

$$Y = w_j . y'_{ij}, \tag{15}$$

where, w_j is the weight of the criterion j.

Step 3: Identify weighted proximity value of each alternative.

$$u_i = \begin{cases} Y_{\max} - Y_i & \text{for } C_1, C_2, ..., C_n \in B \\ Y_i - Y_{\min} & \text{for } C_1, C_2, ..., C_n \in C \end{cases}, \tag{16}$$

where B represents the max criterion and C represents the min criterion.

Step 4: Determine the overall proximity value.

$$d_i = \sum_{j=1}^{n} u_i. \tag{17}$$

Step 5: Ranking the options according to the rule that the alternative with the shortest of d_i is considered the best.

3 Weighting methods

The *MEREC* method calculates the weights of the criteria according to the following steps [18]:

Step 1: Same as the *RAFSI*.

Step 2: Compute the normalized value according to the formula.

– Option A: if j represents the max criterion:

$$h_{ij} = \frac{\min y_{ij}}{y_{ij}}. \tag{18}$$

– Option B: if j represents the min criterion:

$$h_{ij} = \frac{y_{ij}}{\max y_{ij}}. \tag{19}$$

Step 3: Define overall performance of the alternatives.

$$S_i = \ln\left[1 + \left(\frac{1}{n}\sum_{j}^{n} |\ln(h_{ij})|\right)\right], \tag{20}$$

Step 4: Calculate the performance of the alternatives.

$$S'_{ij} = \ln\left[1 + \left(\frac{1}{n}\sum_{k,k\neq j}^{n} |\ln(h_{ij})|\right)\right], \tag{21}$$

Step 5: Determine absolute deviations.

$$E_j = \sum_{i}^{m} |S'_{ij} - S_i|, \tag{22}$$

Step 6: Define the final weights of the criteria

$$w_j = \frac{E_j}{\sum_{k}^{m} E_k}, \tag{23}$$

The *ROC* method calculates the weights of the criteria according to the following steps [22]:

$$w_j = \frac{1}{n}\sum_{k=i}^{n} \frac{1}{k}, \tag{24}$$

The *RS* method computes the weights of the criteria according to the following steps [23]:

$$w_j = \frac{2(n+1-i)}{n(n+1)}, \tag{25}$$

The *EQUAL* method determines the weights of the criteria according to the following steps [24]:

$$w_j = \frac{1}{n}. \tag{26}$$

4 Turning process

In order to compare the *RAFSI* and *PIV* method in multi-criteria decision making, this study applies them to a turning operation. A conventional lathe ECOCA is used to implement the experiments (Fig. 1). The test material is 9XC steel with a diameter of 28 mm and a length of 310 mm. Four parameters were changed at each trial, including the tool holder length, spindle speed, feed rate

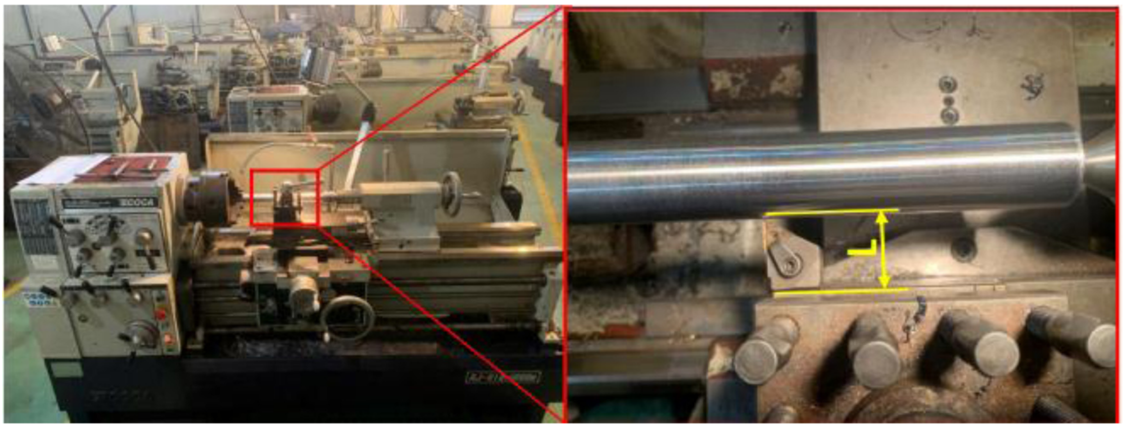

Fig. 1. Photograph of lathe used in experimental investigation.

Table 1. Values of input parameters.

Parameter	Symbol	Unit	Value at level			
			1	2	3	4
Tool holder length	L	mm	25	30	35	40
Cutting speed	n_w	rev/min	659	910	1140	1350
Feed rate	f_d	mm/rev	0.092	0.126	0.187	0.282
Depth of cut	a_p	mm	0.2	0.4	0.6	0.8

and depth of cut. They are changeable by operators of the machine. The values of the input parameters were selected as shown in Table 1, based on reference to a number of studies [13,25]. In addition, the advantages in designing the experimental matrix under the Taguchi method are mentioned in some research [26,27]. Consequently, the Taguchi method was also used in this study so as to design a matrix of sixteen tests as shown in Table 2.

MRR is the material removal rate, which is an important parameter to evaluate the productivity of the machining process. A large value of *MRR* means a high-productivity machining process [28]. *RE* is the roundness error of the cylindrical surface of the work piece. *Ra* is the surface roughness. Both *RE* and *Ra* parameters have a great influence on the working ability as well as the life of the machine parts. The cylindrical surface of the parts after machining with small *RE* and *Ra* is desirable in most machining processes [29,30]. Thus, all three parameters are considered to be the criteria for evaluating the turning process. At each experiment, the *MRR* is calculated according to the formula (27). Where n_w, d, f_d, a_p are the spindle speed, workpiece diameter, feed rate and depth of cut, respectively.

$$MRR = \frac{1}{60} n_w \cdot \pi \cdot d \cdot f_d \cdot a_p. \qquad (27)$$

RE is measured using a dial gauge with an accuracy of 1/1000 (Fig. 2). During the measurement, the position of the work piece shall be adjusted so that, after it has rotated a circle around its center, the measuring head of the round type dial gauge will sweep a circle on the surface of the work piece and this circle is perpendicular to the centerline of the work piece. In order to reduce the random error of the test results during the experiment, three steel samples were used in each trial; the *RE* value at each test specimen is denoted as RE_1, RE_2, and RE_3 respectively, then calculate $RE = (RE_1 + RE_2 + RE_3)/3$. The *Ra* is similarly determined, as $Ra = (Ra_1 + Ra_2 + Ra_3)/3$. Roughness tester SJ-301 (Japanese company Mitutoyo) with accuracy 0.001 μm was used to measure this parameter. During the measurement, the measuring head of the tester will move parallel to the centerline of the part, that is, perpendicular to the cutting velocity vector. The values of the input parameters (*MRR*, *RE*, *Ra*) are presented in Table 3.

The purpose of multi-criteria decision making in this situation is to find one of the sixteen experiments in Table 3 in which the *MRR* is considered to be maximum, *RE* and *Ra* to be considered minimum at the same time. The two methods *RAFSI* and *PIV* combined with the four weighting (such as: *MEREC, ROC, RS*, and *EQUAL*) methods were applied so as to fulfill this task.

5 Multi-criteria decision making

The weights of the criteria *MRR, RE* and *Ra* were determined under the *MEREC* method by applying the formulas from (18) to (23). Regarding the *ROC*, *RS* and *EQUAL* methods, the weights of the criteria were determined according to the respective formulas (24), (25) and (26). The weight values of the criteria based on the different methods are presented in Table 4.

Table 2. Orthogonal array L16.

Trial.	Code value				Real value			
	L	n_w	f_d	a_p	L (mm)	n_w (rev/min)	f_d (mm/rev)	a_p (mm)
1	1	1	1	1	25	659	0.092	0.2
2	1	2	2	2	25	910	0.126	0.4
3	1	3	3	3	25	1140	0.187	0.6
4	1	4	4	4	25	1350	0.282	0.8
5	2	1	2	3	30	659	0.126	0.6
6	2	2	1	4	30	910	0.092	0.8
7	2	3	4	1	30	1140	0.282	0.2
8	2	4	3	2	30	1350	0.187	0.4
9	3	1	3	4	35	659	0.187	0.8
10	3	2	4	3	35	910	0.282	0.6
11	3	3	1	2	35	1140	0.092	0.4
12	3	4	2	1	35	1350	0.126	0.2
13	4	1	4	2	40	659	0.282	0.4
14	4	2	3	1	40	910	0.187	0.2
15	4	3	2	4	40	1140	0.126	0.8
16	4	4	1	3	40	1350	0.092	0.6

Fig. 2. Measuring *RE* with a dial gauge.

After determining the weights of the criteria, the ranking of the alternatives is carried out. First, the ranking of the alternatives on the basis of the *MEREC* method is performed.

The formula (1) is used to build a multi-criteria decision matrix. This matrix is created from column 2, 6 and 10 in Table 3.

Formulas (2) to (7) are used to calculate s_{ij}.

Value of A defined by formula (8) is 8.5, value of H determined by formula (9) is 0.9412.

Values of t_{ij} are identified using the formulas (10) to (12).

Formula (13) is applied to compute $V(Ai)$. The ranking of alternatives on the basis of $V(Ai)$ was conducted.

Table 5 presents the values of some parameters under the *RAFSI* method and rank of the alternatives.

Formulas (14) to (17) are applied to define the values in the *PIV* method, the results are presented in Table 6. The ranking of alternatives on the basis of d_i was carried out and summarized in Table 6.

Therefore, the ranking of the criteria in the case of the criteria weight determined by the *MEREC* method was completed. And the ranking of alternatives according to the remaining three weighting methods (*ROC, RS,* and *EQUAL*) was also finished similarly. The result is presented in Table 7. So as for the convenience of comparing under the different methods, the ranking results of the alternatives in the case of using the *MEREC* method (presented in the Tabs. 5 and 6) are also included in this table.

The data in Table 7 revealed that:

– In the case of the *RAFSI* method: First, the ranking order of all sixteen alternatives is the same as the weights of the criteria is determined by the two methods *MEREC* and *EQUAL*. Next, fourteen out of the sixteen alternatives were not different as the weights of the criteria were defined using the *ROC* and *RS* methods (interchangeably only at 5th and 6th). This shows that the degree of stability achieved upon ranking the criteria is high. The best (rank 1) and the worst solution (rank 16) are the same according to the different weighting methods. It can be explained that the *RAFSI* method mentioned ideal (*AI*) and anti-ideal (*AAI*) values for each criterion. Moreover, the ranks of 2, 13, 14 and 15 also coincide as the different weighting methods are used.

– In the case of the *PIV* method: The ranking results of the alternatives are different as the different weighting methods are applied. This is consistent with the statement in another study [17]. Most importantly, however, alternative 4 was found to be the best in the use of all four different weighting methods. This result coincides with the results using the *RAFSI* method as well.

– Although the different multi-criteria decision making and weighting methods are used, the eight ranking results all indicate that experiment 4 is the best option. For this reason, it can be confirmed that alternative 4 is

Table 3. Result of the experiments.

Trial.	*MRR* (mm^3/s)	RE_1 (μm)	RE_2 (μm)	RE_3 (μm)	*RE* (μm)	Ra_1 (μm)	Ra_2 (μm)	Ra_3 (μm)	Ra (μm)
1	17.777	6	6	5	5.667	0.642	0.689	0.694	0.675
2	67.24	13	13	14	13.333	0.902	0.968	1.076	0.982
3	187.523	23	22	23	22.667	1.522	1.589	1.497	1.536
4	446.508	11	11	11	11.000	0.846	0.802	0.752	0.800
5	73.041	25	24	26	25.000	1.257	1.252	1.301	1.270
6	98.192	28	27	29	28.000	1.102	1.008	0.926	1.012
7	94.263	12	12	13	12.333	2.012	2.018	2.156	2.062
8	148.044	12	11	12	11.667	1.300	1.308	1.304	1.304
9	144.535	37	37	38	37.333	2.010	1.905	1.926	1.947
10	225.735	32	32	32	7.000	0.882	0.868	0.890	0.880
11	61.505	8	8	8	8.000	0.620	0.620	0.611	0.617
12	49.876	5	6	5	5.333	0.656	0.656	0.656	0.656
13	108.981	27	27	26	26.667	2.472	2.466	2.475	2.471
14	49.896	9	8	9	8.667	1.402	1.408	1.384	1.398
15	168.47	27	27	27	27.000	1.288	1.119	1.229	1.212
16	109.252	14	13	14	13.667	0.678	0.655	0.695	0.676

Table 4. Weights of the criteria based on the different weighting methods.

Weight method	*MRR*	*RE*	*Ra*
MEREC	0.3096	0.3408	0.3496
ROC	0.6111	0.2778	0.1111
RS	0.5000	0.3333	0.1667
EQUAL	0.3333	0.3333	0.3333

Table 5. Some parameters under RAFSI method and rank of the alternatives.

Trial.	s_{ij}			t_{ij}			*V(Ai)*	Rank
	MRR	*RE*	*Ra*	*MRR*	*RE*	*Ra*		
1	1.0000	15.8434	15.5307	0.059	0.030	0.030	0.0389	16
2	2.7306	12.2500	13.0469	0.161	0.038	0.036	0.0754	12
3	6.9389	7.8747	8.5647	0.408	0.060	0.055	0.1659	5
4	16.0000	13.3436	14.5194	0.941	0.035	0.032	0.3147	1
5	2.9335	6.7811	10.7168	0.173	0.069	0.044	0.0924	11
6	3.8135	5.3748	12.8042	0.224	0.088	0.037	0.1121	9
7	3.6760	12.7188	4.3091	0.216	0.037	0.109	0.1177	8
8	5.5576	13.0309	10.4417	0.327	0.036	0.045	0.1293	7
9	5.4349	1.0000	5.2395	0.320	0.471	0.090	0.2907	2
10	8.2758	15.2186	13.8722	0.487	0.031	0.034	0.1731	4
11	2.5299	14.7498	16.0000	0.149	0.032	0.029	0.0672	13
12	2.1230	16.0000	15.6845	0.125	0.029	0.030	0.0592	15
13	4.1910	5.9997	1.0000	0.247	0.078	0.471	0.2676	3
14	2.1237	14.4372	9.6812	0.125	0.033	0.049	0.0668	14
15	6.2723	5.8436	11.1861	0.369	0.081	0.042	0.1564	6
16	4.2004	12.0934	15.5227	0.247	0.039	0.030	0.1004	10

Table 6. Some parameters under PIV method and rank of the alternatives.

Trial.	Y_i			ui			d_i	Rank
	MRR	*RE*	*Ra*	*Ra*	*RE*	*MRR*		
1	0.0085	0.0254	0.0443	0.0038	0.0015	0.2053	0.2106	6
2	0.0322	0.0598	0.0645	0.0240	0.0359	0.1816	0.2414	8
3	0.0898	0.1016	0.1008	0.0603	0.0777	0.1240	0.2621	10
4	0.2138	0.0493	0.0525	0.0120	0.0254	0.0000	0.0374	1
5	0.0350	0.1121	0.0834	0.0429	0.0882	0.1789	0.3099	14
6	0.0470	0.1255	0.0664	0.0259	0.1016	0.1668	0.2943	12
7	0.0451	0.0553	0.1353	0.0948	0.0314	0.1687	0.2949	13
8	0.0709	0.0523	0.0856	0.0451	0.0284	0.1429	0.2164	7
9	0.0692	0.1674	0.1278	0.0873	0.1434	0.1446	0.3754	15
10	0.1081	0.0314	0.0578	0.0173	0.0075	0.1057	0.1305	2
11	0.0295	0.0359	0.0405	0.0000	0.0120	0.1844	0.1963	4
12	0.0239	0.0239	0.0431	0.0026	0.0000	0.1899	0.1925	3
13	0.0522	0.1195	0.1622	0.1217	0.0956	0.1616	0.3790	16
14	0.0239	0.0389	0.0918	0.0513	0.0149	0.1899	0.2561	9
15	0.0807	0.1210	0.0796	0.0391	0.0971	0.1332	0.2693	11
16	0.0523	0.0613	0.0444	0.0039	0.0374	0.1615	0.2027	5

Table 7. Ranking alternatives based on different methods.

Trial.	*RAFSI* method				*PIV* method			
	MEREC weight	*ROC* weight	*RS* weight	*EQUAl* weight	*MEREC* weight	*ROC* weight	*RS* weight	*EQUAl* weight
1	16	16	16	16	6	7	9	7
2	12	12	12	12	8	10	10	8
3	5	4	4	5	10	8	5	9
4	1	1	1	1	1	1	1	1
5	11	11	11	11	14	14	14	14
6	9	8	8	9	12	13	13	13
7	8	10	10	8	13	11	12	12
8	7	7	7	7	7	3	3	6
9	2	2	2	2	15	16	16	15
10	4	3	3	4	2	2	2	2
11	13	13	13	13	4	5	7	4
12	15	15	15	15	3	4	6	3
13	3	6	5	3	16	15	15	16
14	14	14	14	14	9	9	11	10
15	6	5	6	6	11	12	8	11
16	10	9	9	10	5	6	4	5

the best. And determining the best option does not depend on the multi-criteria decision-making method as well as the weighting method.
– In order to simultaneously obtain the maximum *MRR*, the minimum *RE* and *Ra*, it is necessary to choose a tool holder length of 25 mm, a spindle speed of 1350 rev/min, a feed rate of 0.282 mm/rev, and a depth of cut of 0.8 mm.

6 Conclusion

This research compares the *RAFSI* and *PIV* method in making multi-criteria decisions. Each of these methods is applied in combination with four different weighting methods, consisting of *MEREC, ROC, RS* and *EQUAL*. The comparison is made during the turning process of 9XC steel, using the three criteria to assess the turning process, including *MRR, RE* and *Ra*. The task is to determine the value of the tool holder length, spindle speed, feed rate and depth of cut for achieving the maximum *MRR*, the minimum *RE* and *Ra*. Some conclusions are drawn as follows:
– Under the *RAFSI* method, the best and worst alternatives do not depend on the weighting methods. The ranking results of the alternatives are the same as the *MEREC* and *EQUAL* methods are applied. The ranking order of the alternatives overlaps fourteen out of sixteen as the weights of the criteria are identified by the two methods *ROC* and *RS*.
– Under the *PIV* method, the best and worst alternatives are independent of the weighting methods as well. The best solution determined by the *PIV* method also coincides with the best alternative defined by the *RAFSI* method. However, the similarity in ranking order of the alternatives using the *PIV* method is less than the *RAFSI* method.
– The *RAFSI* method should be used and the two weighting methods *MEREC* and *EQUAL* should be preferred in order to obtain high stability in ranking alternatives.
– The similarity between Parato multi-objective optimization and multi-criteria decision making is the determination of the best solution. However, if multi-criteria decision making can only determine the best solution among the available solutions, then Pareto multi-objective optimization can also identify the best solution that may be not one of the available solutions.
– So as to have the maximum *MRR* and the minimum *RE* and *Ra* at the same time, it is needed to select the tool holder length, spindle speed, feed rate and depth of cut to be 25 mm, 1350 rev/min, 0.282 mm/rev and 0.8 mm, respectively. It should be noted that these values may change when using experimental systems with different accuracy. However, choosing the best solutions by *RAFSI* method and *PIV* method can still be used and still ensure the accuracy of decision-making results.
– The weights of the criteria do not depend on the ranking order of the criteria under the two methods *MEREC* and *EQUAL*. However, regarding the other two methods (*ROC* and *RS*), it is clear that the weights of the criteria are dependent on the ranking order of the criteria (refer to formulas (24) and (25)). The difference in the criteria order results in the change of the weight of criteria determined by the *ROC* and *RS* methods. Hence, it is necessary to have further studies in the future in order to dig deeper into this change.

List of acronyms

MCDM: Multi-Criteria Decision Making
RAFSI: Ranking of Alternatives through Functional mapping of criterion sub-intervals into a Single Interval
PIV: Proximity Indexed Value
MRR: Material removal rate
RE: Roundness Error
Ra: Roughness Average of a surfaces measured microscopic peaks and valleys
MEREC: Method based on the Removal Effects of Criteria
ROC: Rank Order Centroid
RS: Rank Sum
TOPSIS: Technique for Order Preference by Similarity to Ideal Solution
MOORA: Multiobjective Optimization On the basis of Ratio Analysis
COPRAS: COmplex PRroportional Assessment
WASPAS: Weighted Aggregates Sum Product ASSessment
VIKOR: VIsekriterijumska optimizacijaI KOmpromisno Resenje (in Serbian)
PSI: Preference Selection Index
RIM: Reference Ideal Method
EDAS: Evaluation based on Distance from Average Solution
MARCOS: Measurement Alternatives and Ranking according to Compromise Solution
EAMR: Evaluation by an Area-based Method of Ranking
PEG: Pareto-Edgeworth Grierson
SAW: Simple Additive Weighting

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