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RSMVC: A NEW-SIMPLE METHOD TO SELECT THE CUTTING TOOL BASE ON MULTI CRITERIA

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Selecting the right cutting tool material for the type of workpiece material plays a very important role in the machining process. The efficiency of the machining process is greatly influenced by this selection. The tables in the manuals or the manufacturer's instructions are commonly used documents for the selection of cutting tool materials. Within each of these document types, the cutting tool materials were described by different criteria. So, tool selection is considered as a multi-criteria decision-making activity. The values of the criteria for each type of cutting tool can be a number or a certain range. This study proposes a new method to rank and select cutting tools. First, a ranking of the solutions for each criterion will be performed. This ranking is based on the mean value of the criteria in each solution. Therefore, this method is called "Ranking the Solutions based on the Mean Value of Criteria - RSMVC". The RSMVC method was proven to be a highly reliable method for ranking the cutting tool materials. These results were successfully verified when solving the problems in different cases of cutter material selection.

Keywords: RSMVC method, tool material selection, multi criteria

1 INTRODUCTION

Ranking the solutions to choose the best one is work that needs to be done in all the different fields. When each solution is described by multiple criteria, this work is called the multi-criteria decision making (MCDM) [1-3]. However, with hundreds of available MCDM methods, selecting a method that is considered as a suitable method is a difficult task. The solution that is considered as the best one may be different when using different MCDM methods [1-3]. Therefore, in order to create the reliability when concluding that a certain solution is considered the best one, many studies have simultaneously used different MCDM methods in a specific problem. Only in 2022 and also only in the mechanical field, there have been many studies that used simultaneously many MCDM methods to rank the solutions in a particular problem. Five methods including COCOSO, MABAC, MAIRCA, EAMR, and TOPSIS were simultaneously used to select the best one in the hole turning process [4]. Four methods including TOPSIS, MARCOS, EAMR, and MAIRCA were simultaneously used for multi-criteria decision-making in grinding process [5]. The multi-criteria decision-making in electrical discharge machining process was carried out using simultaneously three methods including MARCOS, TOPSIS, and MAIRCA [6]. Two methods including FUCA and CURLI were simultaneously used in the selection of the lathe [7], ect.

In addition to depending on used MCDM method, the ranked results of the solutions also heavily depend on the determination methods of the weights for the criteria [8]. The ranked results of the solutions may be different when using different weighting methods [9-11].

Thus, it can be said that with a large number of MCDM methods and determination methods of weights, the multi-criteria decision-making is increasingly attracting the attention of the researchers. However, because of this, the selecting a suitable method becomes a difficult task for decision makers.

Selecting the suitable cutting tool material for each type of machining material is a very important work. This work determines the efficiency of the machining process [12]. The selection of the cutting tool in each case must ensure that the selected material has high hardness, high strength, high plasticity, high heat resistance temperature, high chemical inertness, low friction coefficient, small thermal expansion coefficient, high heat transfer coefficient, etc. [13, 14]. However, in reality, these parameters are contradictory, for example, a material with high hardness also with smaller plasticity [15]. On the other hand, the efficiency of one type of cutting tool when combined with each workpiece material will also be different [16]. In other words, for each type of workpiece, a variety of tool materials can be used, but only one of them is considered to be the best. In order to choose the cutting tool material that is considered the most suitable for a material of the workpiece, many criteria need to be considered. This means that tool selection is also a multi-criteria decision-making activity. When selecting the cutting tools according to the criteria, the values of the criteria are often used from the manual tables or as recommended by the manufacturer [12, 17]. In which, the value of the criteria in each selection can be a single number, or a range of values.

When the values of the criteria in each selection are represented as an unique numbers, the decision-making for the selection of cutting tool materials is considered simple, and performed by a number of scientists by different methods such as Milos et al. [18] using the WASPAS method; Shelar et al. [19] using the AHP method; Singaravel et al. [20] using the ARAS method; Maity et al. [21] using the COPRAS-G method; Suresh et al. [22] using the WASPAS method; Nikam et al. [23] applying the SAW method; ect. However, as presented above, all these methods can rank the tool types only when the value of each parameter in each solution is a unique value.

When the values of the criteria in each alternative are within a value interval, the multi-criteria decision making is often more complex. To solve this problem, a number of special data normalization methods have been proposed, including the method of normalizing the data of a criterion according to the value of that criterion in a certain interval [15, 24]. Then, depending on the used MCDM method, these normalized values are used to score the selections in different ways. However, the normalizing the data in this way is quite complicated and the results of the ranking of the solutions are highly dependent on the used data normalization method. If a data normalization method is chosen inappropriately, it will lead to mistakes in ranking the soltuons. And the truly best solution may be not found [2].

Removing the data normalization step will greatly simplify decision making. This paper will propose a new MCDM method to solve this problem. The outstanding advantage of the proposed method in comparing to most other MCDM methods is that there is no need to perform the data normalization. Instead, the ranking of solutions in this method is based on the mean values of the criteria in each solution. Beacuse the ranking of selections is based on the mean of the criteria the method is named Ranking the Solutions based on the Mean Value of Criteria (RSMVC).

Currently, there are a number of MCDM methods to rank the solutions for each criterion such as R method [25, 26], FUCA method [27]. However, both methods only solve with the ranking criteria when their values in each solution is a single number, not consider to the cases where their values are in the interval. The proposed method in this study (RSMVC) was overcome this limitation of these two methods. This method is not only used to rank solutions when the criteria's values to be an interval values, but even when the criteria's values to be a single number, it is alo can be applied. Section 2 of this paper presents the proposed method, and the application cases to evaluate the effectiveness of the proposed method are performed in section 3; The obtained conclusions of this study and the future work are the contents in the final section.

2 PROPOSED METHOD

Step 1: Building the matrix with the solutions and the evaluation criteria for each solution.

$$\begin{array}{cc} \begin{array}{c} A1\\ A2\\ A3\\ A4\\ \vdots\\ Am \end{array} & \left[\begin{array}{ccc} a_{11} \div b_{11} & \cdots & a_{1n} \div b_{1n}\\ a_{21} \div b_{21} & \cdots & a_{2n} \div b_{2n}\\ a_{31} \div b_{31} & \cdots & a_{3n} \div b_{3n}\\ \vdots & \vdots & \vdots\\ \vdots & a_{ij} \div b_{ij} & \vdots\\ a_{m1} \div b_{m1} & \cdots & a_{mn} \div b_{mn} \end{array}\right] \end{array}$$

where: *m* is the number of the solutions, *n* is the number of the criteria, a_{ij} and b_{ij} are the lower limit and upper limit of criterion *j* at solution *i*, respectively.

Step 2: Calculate the mean value of each criterion for each solution by Eq. (1). It should be noted that Eq. (1) is used when the value of the criterion is in the interval $[a_{ij}, b_{ij}]$. In case the criterion value is a single number, this formula is still used for the case $a_{ij} = b_{ij}$.

$$\bar{x}_{ij} = \frac{a_{ij} + b_{ij}}{2} \tag{1}$$

Step 3: Rank the solution for each criterion based on the mean value.

- For the larger the better criterion: The solution with the highest mean is ranked 1, and the solution with the smallest mean is ranked last.
- For the smaller the better criterion: The solution with the smallest mean is ranked 1, and vice versa, the solution with the highest mean is ranked last.

If there are *n* criteria, it needs to be performed *n* ranking time for the solutions.

Step 4: Calculate the score for each solution by Eq. (2).

$$S_i = r_{ij} \cdot w_j \tag{2}$$

where: r_{ij} is the rank of criterion *j* for the solution *i* that is determined in step 3; w_j is the weight of criterion *j*.

Step 5: Rank the solutions, the best solution is the one with the smallest S_i score, and vice versa.

Next sections, the examples that are carried out to evaluate the effectiveness of the proposed method. In those examples, the data were referenced from published studies. In those studies, the multi-criteria decision making was also performed by different *MCDM* methods. Those results will be used to compare with the results when using the proposed method in this paper.

3 APPLICATION CASE

3.1 Example 1

Niu et al. [15] used the COPRAS-G method to rank 5 types of tool materials. Each type is identified and evaluated through ten criteria. The value of each criterion in each criterion is within a certain interval as listed in Table 1. The weights of the criteria were also determined and listed in the last row of this table.

where:

C1: Hardness (HK);

C2: Flexural strength (MPa);

C3: Fracture toughness (MPa $m^{1/2}$);

C4: Heat resistance temperature (K);

C5: Modulus of elasticity (GPa);

C6: Heat transfer coefficient (W/mK);

C7: Coefficient of thermal expansion (μm/(m°C));

C8: Chemical reaction with workpiece material;

C9: Diffusive solubility in workpiece material;

C10: Cost of tool material (USD/kg).

In ten mentioned criteria, the criteria that are from *C1* to *C6* are the larger the better criteria. In contrast, the criteria that are from *C7* to *C10* are the smaller the better criteria. The task of tool selection is finding a solution *Ai* (with *i = 1 – 5*) that simultaneously ensures the criteria *C1* to *C6* is the maximum, and *C7* to *C10* is the minimum.

Table 1. The criteria of the cutting tool (example 1) [15]

No.	*C1*	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*	*C9*	*C10*
A1	1248-1526	1100-1500	14-20	1100-1300	621-759	88.2-107.8	5.85-7.51	1.8-2.2	0-0.06434	54-66
A2	1620-1980	900-1400	7.9-11.6	1300-1500	410-496	15.3-18.7	6.93-8.47	1.8-2.2	0-0.01082	16.2-19.8
A3	1530-1870	500-700	2.78-8	1600-1700	333-407	27-33	4.85-5.97	0.9-1.1	0-2.87×10^{-24}	136.9-167.33
A4	2295-2805	700-1100	5.7-8	1300-1500	279-341	37.8-46.2	2.79-3.14	0.9-1.1	0-0.01013	360-440
A5	3000-5000	500-1200	5-9	1600-1800	765-935	11.7-14.3	4.32-5.28	2.7-3.3	0-0.00034	777.6-950.4
Weight	0.023	0.054	0.01	0.073	0.03	0.096	0.04	0.0158	0.402	0.25

Applying the Eq. (1), the mean values of the criteria were calculated at each selection and listed in Table 2.

Table 2. The average of the criteria at each solution (example 1)

No.	$\bar{x}_{ij}$									
	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*	*C9*	*C10*
A1	1387	1300	17	1200	690	98	6.68	2.000	0.032	60
A2	1800	1150	9.75	1400	453	17	7.7	2.000	0.005	18
A3	1700	600	5.39	1650	370	30	5.41	1.000	1.43×10^{-24}	152.1
A4	2550	900	6.85	1400	310	42	2.965	1.000	0.005	400
A5	4000	850	7	1700	850	13	4.8	3.000	2×10^{-4}	864

Rank the selections for each criterion based on the mean values. It should be noted that:

For the criteria *C1*, *C2*, *C3*, *C5*, *C6*, *C7*, *C9,* and *C10:* Because the values of these criteria in the selections are completely different, the ranking of the criteria is conducted as in step 3.

For criterion *C4*: *C4* at *A5* is the largest, so *A5* ranked 1st; next is the *C4* value at *A3*, so *A3* ranked 2; *C4* at *A3* and *A4* are equal to each other, so both *A3* and *A4* are ranked 3.5 (the average of 3 and 4); *C4* at *A1* is the smallest, so *A1* ranked 5.

For criterion *C8*: *C8* at *A5* is the largest, so *A5* ranked 5; *C8* at *A3* and *A4* are equal to each other, so two selections are ranked 1.5 (the average of 1 and 2); *C8* at *A1* is equal to *C8* at *A2*, so both *A1* and *A2* rated 3.5 (the average of 3 and 4).

The ranked results of the selections for each criterion were listed in Table 3.

Table 3. Ranking the solutions for each criterion (example 1)

No.	r_{ij}									
	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*	*C9*	*C10*
A1	5	1	1	5	2	1	4	3.5	5	2

No.	r_{ij}									
	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*	*C9*	*C10*
A2	3	2	2	3.5	3	4	5	3.5	4	1
A3	4	5	5	2	4	3	3	1.5	1	3
A4	2	3	4	4.5	5	2	1	1.5	3	4
A5	1	4	3	1	1	5	2	5	2	5

Applying the Eq. (2), the score (S_i) of each selection was calculated and listed in Table 4. The ranked results using *COPRAS-G* method were listed in this table.

Table 4. Ranking the solutions (example 1)

No.	S_i	Rank	
		RSMVC	*COPRAS-G* [15]
A1	3.4349	5	4
A2	3.0341	2	2
A3	2.2777	1	1
A4	3.1664	4	5
A5	3.0869	3	3

So, the proposed method in this study also shows the best selection as the *COPRAS-G* method. On the other hand, the 2nd and 3rd ranks coincide when ranked by these two methods. Thus, it can be said that the proposed method was succeeded in solving the problem of this example (determining the best selection).

However, to evaluate the comprehensive effectiveness of a proposed *MCDM* method, the last thing to do is analyzing the stability in ranking the solutions [28, 29]. The stability of the rating results of solutions is simply understood as how the ranking results of solutions will change with different scenarios. The methods for generating different scenarios may be changing the weight of the criteria or removing a selection from the list of solutions [30]. The removal method of a selection out of the list of solutions was used in this paper.

In this case, the best selection (*A3*) was removed from the list of the solutions. Now, there are only four solutions: *A1*, *A2*, *A4*, and *A5*. If there were no rank inversion phenomeno, then *A2* would rank 1, *A5* would rank 2, *A4* would rank 3, and *A1* would rank 4. This is the perfect situation (*PS*). Figure 1 shows a graph comparing the ranked results of four solutions between the real ranking (*R*) and the ranking in the perfect situation (*PS*).

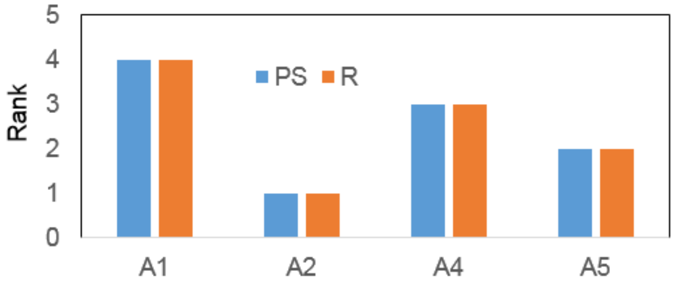

Fig. 1. Ranking the solutions after removing the solution A3

The results from Figure 1 show that after removing *A3* from the list of solutions, the ranking results of the solutions completely overlap with the perfect situation. It means that the rank reversion phenomeno does not occur in any solution. This results that is an amazing result was achieved in this example. In summary, it can be affirmed that the proposed method was absolute successfully applied in this example.

3.2 Example 2

Li et al. [31] used the AHP method to rank five tool materials. Each material is ranked by seven criteria. The value of each criterion for the selection is in both the form of a single number, and the form of an interval as shown in Table 5. The weights of the criteria were also determined and listed in the last row of this table.

Table 5. The criteria of the cutting tools (example 2) [31]

No.	*C1*	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*
A1	14.5-15	590-630	1500-1700	10.8	800-1200	100	5.4
A2	14.5-14.9	642	1400	14	1000	103	5.9
A3	3.5-4.2	680-810	4000-5000	6.8-8.8	600	560	4.2-4.9
A4	3.4-4.3	580-680	3000-4500	3.7-6.3	1500	40-100	3.6-4.9

No.	*C1*	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*
A5	3.8-5	300-400	1800-2500	2-4	1300-1800	30-40	7.5-8
Weight	0.11	0.182	0.28	0.144	0.169	0.08	0.048

where:

C1: Materials density (g/mm^3);

C2: Young's modulus (GPa);

C3: Hardness (HV);

C4: Fracture toughness (MPa.m$^{1/2}$);

C5: Thermal stability;

C6: Thermal conductivity (W/(m.^{0}C));

C7: Thermal expansion coefficient (μm/(m°C));

In seven criteria, except *C7*, all the remaining criteria are in the form of the larger the better criteria.

The ranking process was performed as for example 1. The ranked results of the selections were listed in Table 6. The ranked results using *AHP* method were listed in this table.

In this example, both the best and worst selections were determined like those ones when using the *AHP* method. Thus, once again, it can be confirmed that the proposed method was succeeded in selecting the best solution.

Table 6. Ranking the solutions (example 2)

No.	*Si*	Rank	
		RSMVC	AHP [31]
A1	3.1875	4	3
A2	3.0305	3	2
A3	2.3795	1	1
A4	2.8385	2	4
A5	3.564	5	5

Conduct a stability check of the solution rank results when removing a solution from the list of solutions. In this example, the worst solution (*A5*) was removed. Now, there are only four solutions including *A1*, *A2*, *A3*, and *A4*. If there is no rank inversion phenomeno (the perfect situation), the ranking results for these four solutions are the same as in Table 6, i.e. *A1* ranked 4, *A2* ranked 3, *A3* ranked 1, and *A4* ranked 2. Figure 2 shows a comparing graph of four solutions' ranking between the real ranks (*R*) results and the ranks in the perfect situation (*PS*).

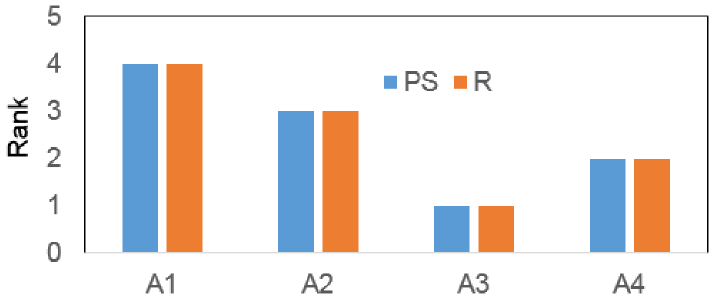

Fig 2. Ranking the solutions after removing the solution A5

The results from Figure 2 show that after removing *A5* from the list of solutions, the ranking results of the solutions also completely coincide with the ranking results in the perfect situation. That mean the phenomenon of rank reversal did not occur in any solutions. Once again, the miracle happened. In summary, it can be again affirmed that the proposed method was successfully applied in this example.

3.3 Example 3

Calıskan [32] simultaneously used the EXPROM2 and VIKOR methods to rank twelve types of tool materials. Seven criteria were used to evaluate cutting tool materials. In each selection, the values of each criterion are unique numbers as presented in Table 7.

The weights of the criteria were also determined and also included in the last row of this table.

where:

C1: Hardness (GPa);

C2: Young's modulus (GPa);

C3: Elastic recovery (%);

C4: Friction coefficient;

C5: Critical load (N);

C6: Coatings' plastic deformation;

C7: Wear resistance;

Except for criterion *C4*, all the remaining six criteria are in the form of the larger the better criteria.

The ranking process was also performed like the steps in example 1. The ranked results of the solutions were listed in Table 8. The ranked results using *EXPROM2* and *VIKOR* methods were listed in this table.

In this example, the best solution that was determined by the proposed method is similar to the best one when using two methods *EXPROM2* and *VIKOR*. On the other hand, all three methods simultaneously identified the worst solutions (rank 12) and the ranked solution 11. Thus, once again, it can be confirmed that the proposed method was succeeded in selecting the best solution.

Table 7. The criteria of the cutting tools (example 3) [32]

No.	*C1*	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*
A1	34	380	60	0.6	30	0.089	0.272
A2	31	380	59	0.49	50	0.082	0.206
A3	20	280	49	0.45	41	0.071	0.102
A4	23	300	46	0.45	46	0.077	0.135
A5	19	270	45	0.45	46	0.07	0.094
A6	30	370	53	0.52	22	0.081	0.197
A7	19	270	43	0.51	87	0.07	0.094
A8	25	340	47	0.45	90	0.074	0.135
A9	17	280	40	0.5	67	0.061	0.063
A10	23	300	48	0.52	54	0.077	0.135
A11	20	260	46	0.43	37	0.077	0.118
A12	19	280	44	0.45	41	0.068	0.087
Weight	0.15	0.128	0.13	0.156	0.153	0.16	0.129

Table 8. Ranking the solutions (example 3)

No.	Si	Rank		
		RSMVC	EXPROM2 [32]	VIKOR [32]
A1	4.3090	2	2	5
A2	3.1730	1	1	1
A3	6.8550	7	8	6
A4	5.5285	4	5	3
A5	8.3105	9	10	10
A6	5.5440	5	4	7
A7	8.6600	10	9	9
A8	4.3950	3	3	2
A9	9.4750	12	12	12
A10	5.8375	6	6	4
A11	6.9800	8	7	8
A12	8.8545	11	11	11

Similar to the above examples, the stability checks of the solution ranking results is done by removing a solution out of the list of solutions. Any ranked solution would be removed from the list. To make a difference with the two above examples, in this example, the best solution (*A2*) and the worst solution (*A9*) are kept in the list of solutions. Randomly select another solution to remove from the list, assuming, the 9th ranked solution (*A5*) is removed from the list of solutions. Now, there are only eleven solutions. If the perfect situation occurs, the ranking orders of the solutions including *A1*, *A2*, *A3*, *A4*, *A6*, *A7*, *A8*, *A9*, *A10*, *A11*, and *A12* were rank 2, rank 1, rank 7, rank 4, rank 5, rank 9, rank 3, rank 11, rank 6, rank 8, and rank 10, respectively.

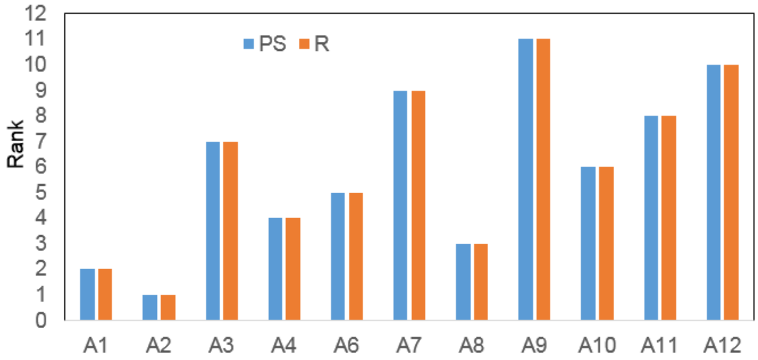

Fig. 3. Ranking the solutions after removing the solution A5

Figure 3 shows a comparing chart of the ranking results of the eleven solutions between the real ranking (*R*) and the ranking in the perfect situation (*PS*).

According to the results from Figure 3: After removing *A5* from the list of solutions, the ranking results of solutions completely coincide with those ones in the perfect situation. That mean the rank inversion phenomeno does not occur in any solutions. Once again, the miracle happened.

The evaluation of the effectiveness of the proposed method was carried out in three different examples. The number of solutions, the number of criteria in the cases are not the same. The format of the criteria is not the same in all cases. In case 1, the values of the criteria in all the solutions are an interval. In the second case, the values of the criteria are of both types, the form in an interval, and the form being a single value. In the third case, the value of the criteria in the solutions is always a number. The analysis of the stability of the ranking results of the solutions in each case was also done with different scenarios, in case 1, the best solutions was removed from the list of solutions. The worst solution was removed from the list of solutions in case 2, one random solution was removed from the list of solutions in case 3. Although many differences were considered in three examples, but great things were achieved in all three examples: (1) the best solution was determined always similar to the solution when using other *MCDM* methods; and (2) do not find any rank inversion phenomena for all solutions in all three cases. These obtained results form a solid conclusion that the proposed method was very successful when applied in these cases. The obtained results show the correctness of the implemented methodology.

Although the difference between the *RSMVC* method and the *R* methods and the *FUCA* method is not too much, it solves a problem that both methods have not mentioned (when the value of the criteria to be an interval). The effectiveness when using the *RSMVC* method was also confirmed through the above analysis. Therefore, the proposal of this method should be acknowledged.

4 CONCLUSION

Selecting the cutting tool materials is a complex task with many criteria. The values of the criteria at each solution can be both a single number or an interval. A new method for multi-criteria decision making was proposed in this study called RSMVC. The effectiveness of the proposed method was verified in three cases with many differences such as different number of criteria, different types of criteria, different scenarios when analyzing the stability in ranking the solutions, etc. The results confirmed that when using the proposed method, the best solution was determined always similar to the best one when using other MCDM methods. It is also very interesting that it was confirmed that there is not any rank reversal when using the proposed method. Accordingly, the proposed method was verified to be suitable for multi-criteria decision making, firstly in the selection of cutting tools. Moreover, when applied in other fields, it is also expected to bring success.

The limitation of the proposed method in this study (RSMVC method) is that it is only used to rank the solutions when the criteria are the quantitative (either a number or within a range of values). Ranking the solutions when the criteria are in qualitative form is the further works of this study.

In addition, in this study, the weights of the criteria were used according to their values in published studies. The analysis of stability in ranking the solusions when using simultaneously many different weighting methods is also a further work of this study. Also, if a limitation of the RSMVC method is found, instead of criticism, please suggest the improvements to make it better.

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