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APPLICATION OF THE COLLABORATIVE UNBIASED RANK LIST INTEGRATION METHOD TO SELECT THE MATERIALS

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Abstract:
For a machining processes, the material selection that is very important, greatly affect both on the economic and technical efficiency of these processes. The selection of each material often was considered many criteria, which have different values in different materials. Multi-criteria decision making that is a technique is used to slove with situations of this type. The collaborative unbiased rank list integration that is a recently proposed multi-criteria decision making method and has only used in a handful of published studies. In this study, *this* method was used to select the materials for the industrial fields. Material selection in three different areas was performed. In each case, the ranking results of the solutions by the collaborative unbiased rank list integration method were compared with those ones of other methods. The results showed that this method is completely reliable when using for material selection with the considering of multiple criteria. Moreover, the strength of this method is that it does not occur any ranking reversion phenomenon even when considered in different scenarios.

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1. INTRODUCTION

The selection of material with the object of manufacture and the material of the working tool affects on many aspects of the products [1], and greatly affects on the efficiency of the machining process [2-4]. The selection of suitable materials that often must consider multiple criteria simultaneously and is considered a multi-criteria decision-making process [5-7]. This research direction was attracted the interest of many scientists with different used Multi-Criteria Decision Making *(MCDM)* methods [8-10]. In which, some studies use only one *MCDM* method, but some studies use simultaneously multiple methods. However, when using different methods, the obtained results are often different. Up to now, there has not been any study with sufficient power to fully explain why the effectiveness of *MCDM* methods to be different. But many researchers believe that the two main points leading to the difference include the data normalization method in different *MCDM* methods are different and the weight determination method are also different in different *MCDM* methods [11-13]. Thus, if the multi-criteria decision making does not need to do the works including data normalizing and determining the weights for the criteria, the above problems will be eliminated.

Collaborative Unbiased Rank List Integration (*CURLI)* is known as an *MCDM* method that does not need to normalize the data nor determine the weights for the criteria. This method was first proposed in 2016 to rank applicants in a medical school [14]. It was also successfully used to rank the plans in surface grinding process [15]. When using to rank the turning process, it was also shown to be an accurate method in comparing to Pareto-Edgeworth Grierson (*PEG)* and better than the Preference

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Selection Index *(PSI)* method [16]. Recently, this method was also confirmed to have the same accuracy as the Ranking method for multi-attribute (*R)* and COmbinative Distance-based Assessment *(CODAS)* methods when using to rank the robots, and to have the same accuracy as *R*, Simple Additive Weighting *(SAW)*, Weighted Aggregates Sum Product Assessment *(WASPAS)*, Technique for Order Preference by Similarity to Ideal Solution (*TOPSIS*), Vlsekriterijumska optimizacijal KOmpromisno Resenje (*VIKOR)*, Multiobjective Optimization On the basis of Ratio Analysis *(MOORA)*, COmplex PRroportional Assessment *(COPRAS)*, and Proximity Indexed Value *(PIV)* methods in ranking the turning processes, to have the same accuracy as *R* and *MABAC* methods in ranking bridge construction solutions [17]. However, in addition to a few above-mentioned studies, there have not been more any studies that applied *CURLI* method was published. The application of this method to select the industrial materials is also a great contribution to the scientific treasure. This study was conducted with the motivation that comes from this aspect.

On the other hand, in all the studies that have applied the *CURLI* method published, the authors only compare the ranked results when using this method with other *MCDM* methods in choosing the best solution, but not perform the stability analysis of the ranked results when using this method. It can be seen as a shortcoming in those studies. A solution is only considered the best one if it retains its position as the best in different scenarios. To prove this issue, a stability analysis method is needed [18, 19]. The stability of the ranking results when using a certain *MCDM* method is understood as how the ranking results of the solutions will change when different scenarios occur. Different scenarios can occur such as when the weight of the criteria is changed, or a solution is removed from the list of solutions [20]. The stability analysis in ranking the solutions when using *CURLI* method has not been proposed in any publication. In this study, this gap will be filled. This is also a motivation for this study to be carried out.

2. LITERATURE REVIEW

As mentioned above, *MCDM* methods have used quite a lot in the ranking the materials in many different fields.

The *TOPSIS* method has been used to select the green materials in the construction field [21], to select the materials for manufacturing the dashboards of the cars [22], to rank the materials in the biomedical applications [23], to select the energy-saving materials [24], to select the materials fabrication of gears [25], to select the heat pump materials [26], ect. Martinez-Gomez et al. [27] used the Operational Competitiveness Rating Analysis *(OCRA)* method to rank the materials in manufacturing the cookware. Sofuoglu [28] used the Reference Ideal Method (*RIM)* to select the type of biomaterial. Torabi and Shokr [29] used Common Weight Data Envelopment Analysis *(CWDEA)* method to rank the materials in manufacturing the flywheels, ect.

However, if multi-criteria decision-making is performed by only one *MCDM* method, the reliability of decision-making results cannot be guaranteed [30, 31]. From these limitations, several studies were also used simultaneously several methods to select materials in different situations.

Two methods including *VIKOR* and ELimination and Choice Translating Reality *(ELECTER)* were found to be equally effective when using to rank the materials in the sugar industry [32]. When using to rank the tool holder materials in milling processes, the Grey Relational Analysis *(GRA)* and *MOORA* methods were found to be equally effective [33]. Anojkumar et al. [34] used two methods *TOPSIS* and *VIKOR* to rank pipe materials in the sugar industry. The ranked results also showed that these two methods are equally effective. Three methods including *TOPSIS*, *COPRAS*, and Additive Ratio ASsessment *(ARAS)* were also found to be equally effective when using to rank the materials in manufacturing the gears [35]. Petković et al. [36] concluded that three methods *TOPSIS*, *COPRAS*, and *WASPAS* to be equally effective when using to select the materials in manufacturing the hard coatings, ect.

Thus, when ranking the materials, the identification of several *MCDM* methods with equivalent efficiency has created a certain confidence in the ranking results, as well as created confidence for decision makers when using the *MCDM* method. However, in practice, these results do not always like those ones. It can be said that because there have been some studies showing the effectiveness of *MCDM* methods to be different when using to select the materials.

Singh et al. [37] used simultaneously three methods including *TOPSIS*, Modified – TOPSIS (*M-TOPSIS*), and Fuzzy TOPSIS (*FTOPSIS*) to select the raw materials for the manufacturing the paper and pulp in India. This study showed that the ranked results of the solutions when using *FTOPSIS* method have higher reliability than those ones when using other two methods. Ercan and Bilal [38] used five methods including Analytic Hierarchy Process *(AHP)*, *SAW*, *TOPSIS*, *ELECTER*, and Best Worst based Simple Additive Weighting *(BWSAW)* to rank the materials for countermeasure flare systems. They confirmed that three methods *AHP*, *SAW*, and *BWSAW* were equivalent and better than other two. Rai et al. [39] improved the *VIKOR* method based on the regexp theory to rankthe materials in manufacturing the flywheels. They found that the modified version of the *VIKOR* method was more accurate than the original one. Bhaskar and Kudal [40] simultaneously used five methods including *SAW*, *MAHP*, *M-TOPSIS*, *TOPSIS*, and *VIKOR* to select the materials to coat the AISI 4140 steel substrate. They determined that the best solution when using the *M-TOPSIS* method was different to the best one when using the other four methods, ect.

Thus, it seems that the ranked results of the solutions are not the same when using different *MCDM* methods. It is believed that this difference is due to the use of different methods of normalizing the data or the use of different methods of the weight determination. *CURLI* is a method that does not need to do both these tasks (normalize the data and determine the weights for the criteria), so it was chosen for use in this study.

The section 3 of this study presents the steps when applying the *CURLI* method. Some examples that were used the *CURLI* method to rank the materials in different fields are presented in section 4. In each of those examples, the ranked results of the solutions by the *CURLI* method were also presented. To compare with other *MCDM* methods, the stability analysis of ranked results was also performed in each case. The last section of this paper presents the conclusions and what needs to be done in the future.

3. CURLI METHOD

The *CURLI* method is used to rank the solutions according to the following steps [14-17].

Step 1: Building the decision matrix as presented in Table 1.

Table 1. Decision matrix

No.	C_1	C_2	C_j	C_4
A_1	x_{11}	x_{12}	x_{1j}	x_{1n}
A_2	x_{21}	x_{22}	x_{2j}	x_{2n}
A_i	x_{i1}	x_{i2}	x_{ij}	x_{im}
A_m	x_{m1}	x_{m2}	x_{mj}	x_{mn}

Where: m is the number of the solutions, n is the number of the criteria, and x_{ij} the value of criterion j at solution m.

Step 2: Building n square matrices with order m. For each of these square matrices, the scores of the solutions for each criterion will be scored in the following way:

Example at the cell corresponding to row t and column k (with $1 \leq t, k \leq m$) of the criterion j:

+ If the value of criterion j at A_t is worse than at A_k, then in that cell, we enter the value -1;

+ If the value of criterion j at A_t is better than at A_k, then in that cell, we enter the value 1;

+ If the value of criterion j at A_t is equal to at A_k, then in that cell, we enter the value 0;

+ Leave the blank the cells on the main diagonal of the matrix (when $t = k$).

After scoring for n criteria, we get n square matrices with order m, and call those matrices to be the scoring matrix for each criterion.

Step 3: Add up the n obtained matrices from step 2 to get a matrix called the process scoring matrix.

Step 4: Change the positions of rows and columns in the *"process scoring matrix"* so that the number of negative elements above the main diagonal is the largest. Then the solution in the top row is the best one, and vice versa.

4. SELECTION OF THE MATERIAL IN SEVERAL CASES

4.1 Case 1: Selection of the material to make the protective panels on cars

The data on the properties of the five materials that were used as protective panels on automobiles were used in this case as presented in Table 2 [41, 42].

The protective plate is attached to the front and rear of the cars, it has the effect of absorbing the impact force in small collisions, to limite the damage to the cars. Five criteria are used to describe the panel material including compressive strength (*C1*), bending modulus (*C2*), hardness (*C3*), Charpy impact toughness (*C4*), elongation (*C5*) and cost (*C6*). In addition to *C5* and *C6*, the remaining four criteria are the bigger the better ones.

Rank the solutions in Table 2 according to the *CURLI* method. First, the scoring of solution for each criterion is performed, the results are presented from Tables 3 to Table 8.

Table 2. Data of case 1 [41, 42]

No.	*C1*	*C2*	*C3*	*C4*	*C5*	*C6*
A1	20	700	92	1	500	78
A2	40	1500	92	1	100	84
A3	65	2500	105	2.18	30	114
A4	130	3100	93	3	50	153
A5	70	2500	90	0.6	7	1300

Table 3. Scoring matrix of criterion *C1* (case 1)

No.	*P1*	*P2*	*P3*	*P4*	*P5*
A1		1	1	1	1
A2	-1		1	1	1
A3	-1	-1		1	1
A4	-1	-1	-1		-1
A5	-1	-1	-1	1	

Table 4. Scoring matrix of criterion *C2* (case 1)

No.	*P1*	*P2*	*P3*	*P4*	*P5*
A1		1	1	1	1
A2	-1		1	1	1
A3	-1	-1		1	0
A4	-1	-1	-1		-1
A5	-1	-1	0	1	

Table 5. Scoring matrix of criterion *C3* (case 1)

No.	*P1*	*P2*	*P3*	*P4*	*P5*
A1		0	1	1	-1
A2	0		1	1	-1
A3	-1	-1		-1	-1
A4	-1	-1	1		-1
A5	1	1	1	1	

Table 6. Scoring matrix of criterion *C4* (case 1)

No.	*P1*	*P2*	*P3*	*P4*	*P5*
A1		0	1	1	-1
A2	0		1	1	-1
A3	-1	-1		1	-1
A4	-1	-1	-1		-1
A5	1	1	1	1	

Table 7. Scoring matrix of criterion *C5* (case 1)

No.	*P1*	*P2*	*P3*	*P4*	*P5*
A1		1	1	1	1
A2	-1		1	1	1
A3	-1	-1		-1	1
A4	-1	-1	1		1
A5	-1	-1	-1	-1	

Table 8. Scoring matrix of criterion *C6* (case 1)

No.	*P1*	*P2*	*P3*	*P4*	*P5*
A1		-1	-1	-1	-1
A2	1		-1	-1	-1
A3	1	1		-1	-1
A4	1	1	1		-1
A5	1	1	1	1	

Add the matrices from Tables 3 to Table 8 to create a process scoring matrix as presented in Table 9.

Table 9. Scoring matrix of process (case 1)

No.	*P1*	*P2*	*P3*	*P4*	*P5*
A1		2	4	4	0
A2	-2		4	4	0
A3	-4	-4		0	-1
A4	-4	-4	0		-4
A5	0	0	1	4	

Move the rows and columns in Table 9 so that the number of elements above the main diagonal with negative values is the largest, the result is a matrix as shown in Table 10.

Table 10. Scoring matrix of process after moving the rows and columns

No.	*P4*	*P3*	*P2*	*P5*	*P1*
A4		0	-4	-4	-4
A3	0		-4	-1	-4
A2	4	4		0	-2
A5	4	1	0		0
A1	4	4	2	0	

According to the data in Table 10, the ranking order of solutions is *A4* > *A3* > *A2* > *A5* > *A1*. Table 11 presents the ranking results of the solutions when using the *CURLI* method, the Preference Ranking Organization METHod for Enrichment Evaluation *(PROMETHEE)* method [41], and the Evaluation based on Distance from Average Solution *(EDAS)* method [42].

Table 11. Ranked results of the solutions using different methods (case 1)

No.	*CURLI*	*PROMETHEE* [41]	*EDAS* [42]
A1	5	5	5
A2	3	3	3
A3	2	2	2
A4	1	1	1
A5	4	4	4

The data in Table 11 show that when using the *CURLI* method, the ranking results of all five solutions are consistent with the ranking results when using *PROMETHEE* and *EDAS* methods. Therefore, it is confirmed to be successful in this study.

However, as mentioned in the introduction section, in order to evaluate the effectiveness of an *MCDM* method, it is not enough to simply use it to find the best solution. To evaluate the effectiveness of an *MCDM* method, in addition to verifying that it shows the best solution, it is also necessary to test its stability under different scenarios. Two methods commonly used to generate different scenarios are changing the weights for the criteria and removing a solution from the list of solutions [40]. However, when using the *CURLI* method, determining the weights for the criteria is not a concern, so the method of removing a solution from the solution list will be used in this study.

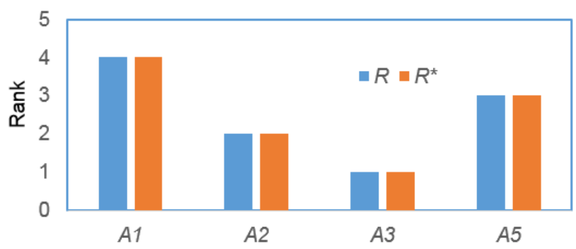

Fig. 1. Ranked results of the solutions afer removing *A4* solution

The best solution (*A4*) was removed from the list of solutions. Assuming no rank inversion phenomenon occurs, the ranking order of solutions is *A3* > *A5* > *A2* > *A1*, this is called the perfect case. The ranking of the remaining four solutions (including *A1*, *A2*, *A3*, and *A5*) is conducted from the beginning. Fig. 1 shows the actual ranking after recalculating (*R*) and the ranking under perfect conditions (R^*).

The results in Fig. 1 show that the ranking results of the four solutions are completely identical between the actual condition and with the perfect condition. It means that there is no ranking reversion phenomenon in any of the solutions. At this point, we can firmly confirm that, in this case, the *CURLI* method was successful in ranking the materials in manufacturing the protective panels on cars.

4.2 Case 2: Selection of the material to manufacturing the gears

The data on the properties of the nine materials that were used in manufacturing the gear were used in this case as shown in Table 12 [42-44]. The criteria for evaluating the materials include core hardness (*C1*), strength (*C2*), fatigue strength (*C3*), bending strength (*C4*), and tensile strength (*C5*). Except for *C1* which is the smaller the better criterion, all other criteria are in the form of the larger the better criteria.

Table 12. Data of case 2 [42-44]

No.	*C1*	*C2*	*C3*	*C4*	*C5*
A1	200	200	330	100	380
A2	220	220	460	360	880
A3	240	240	550	340	845
A4	270	270	630	435	590
A5	270	270	670	540	1190
A6	240	585	1160	680	1580
A7	315	700	1500	920	2300
A8	315	750	1250	760	1250
A9	185	500	430	430	625

Ranking the solutions for the data in Table 12 using *CURLI* method was performed as in the section 4.1. The results of the ranking of solutions were included in Table 13. The results of ranking of solutions according to other methods including *EDAS* [42], *TOPSIS* [43], and EXtended Preference Ranking Organization METHod for Enrichment Evaluation II *(EXPROM2)* [44] were also summarized in this table.

Table 13. Ranked results of the solutions using different methods (case 2)

No.	*CURLI*	*EDAS* [42]	*TOPSIS* [43]	*EXPROM2* [44]
A1	9	9	9	9
A2	8	8	8	8
A3	7	7	6	6
A4	5	5	5	5
A5	4	4	4	4
A6	3	3	3	3
A7	1	1	1	1
A8	2	2	2	2
A9	6	6	7	7

The data in Table 13 show that the ranking results of the solutions when using the *CURLI* method are completely consistent with those ones when using the *EDAS* method. When comparing with two other methods including *TOPSIS* and *EXPROM2*, the ranking results of solutions by *CURLI* method also have very little difference to these two methods. Seven of the nine solutions are exactly the same when using all three methods (*CURLI*, *TOPSIS*, and *EXPROM2*). There is only a difference in solutions *A3* and *A9*. However, this does not affect on finding the best solution (*A7*). So, in this case, again, the *CURLI* method found the best solution just like the other methods.

The evaluation of stability in the ranking of solutions by the *CURLI* method was again performed. In this case, the worst solution (*A1*) was removed from the list of solutions. Fig. 2 presents a comparison chart of the ranking results of the solutions after removing *A1* in the two cases including under perfect conditions (R^*) (when no ranking reversion phenomenon occurs) and in real conditions (*R*) (the ranking is performed from begining).

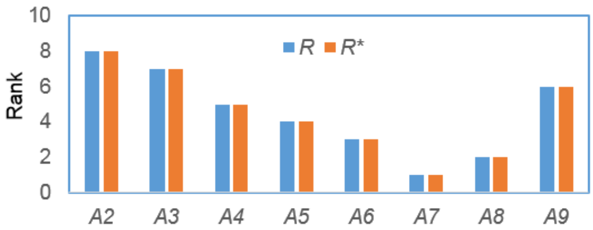

Fig. 2. Ranked results of the solutions afer removing *A1* solution

Fig. 2 shows that the ranking results of the eight solutions (from *A2* to *A9*) are completely coincidental when ranking in real and perfect conditions. It means that no ranking reversion phenomenon was occurred. Again, with this example, we can also firmly conclude that the *CURLI* method was successfully applied in selecting the material in manufacturing the gears.

4.3 Case 3: Selection of the material of the cutting tools

Data on the types of cutting tool materials were used in this case as given in Table 14 [45]. The criteria that were used to evaluate the cutting tool materials include hardness (*C1*), Young's modulus (*C2*), elastic recovery (*C3*), friction coefficient (*C4*), load capacity (*C5*), the deformation-resistance degree index of the coating (*C6*), and the wear-resistance degree index of the coating (*C7*). In the seven criteria, only *C4* is the smaller the better criterion, all the remaining criteria are the larger the better criteria.

The *CURLI* method is again used to rank the solutions in Table 14. The ranking is carried out in the same way as in section 4.1. The ranked results of the solutions are presented in Table 15. The ranked results of the solutions when using the two methods *EXPROM2* and *VIKOR* [45] were summarized in this table.

Table 14. Data of case 3 [45]

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	0.7	0.094
A6	30	370	53	0.52	22	0.081	0.197
A7	19	270	43	0.51	47	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

According to the data in Table 15, the ranked results of the solutions when using the *CURLI* method completely coincide with the results when using the *EXPROM2* method. The rank 1, rank 10, rank 11 and rank 12 solutions also coincide when using both two method *CURLI* and *VIKOR*. The determined best and worst solutions also coincide when using all three methods. Thus, the ranked results of the solutions by the *CURLI* method are confirmed to be completely accurate.

Table 15. Ranked results of the solutions using different methods (case 3)

No.	*CURLI*	*EXPROM2* [45]	*VIKOR* [45]
A1	2	2	5
A2	1	1	1
A3	8	8	6
A4	5	5	3
A5	10	10	10
A6	4	4	7
A7	9	9	9
A8	3	3	2
A9	12	12	12
A10	6	6	4
A11	7	7	8
A12	11	11	11

Once again, the evaluation of stability in ranking solutions by *CURLI* method is performed. In this case, any solution was removed from the list of solutions, assuming the solution *A5* (ranked 10) was removed from the list of solutions.

Fig. 3 presents a comparison chart of the ranking results of the solutions after removing *A5* in two cases, one is under perfect conditions when no ranking reversion phenomenon occurs (R^*) and two in real conditions when the ranking of solutions is perfomed from begining (*R*).

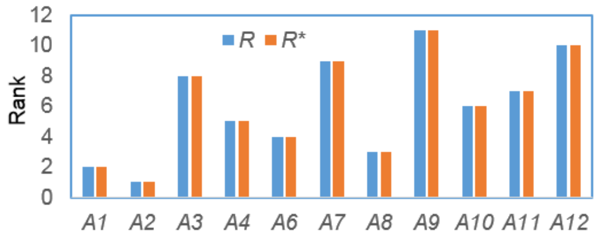

Fig.3. Ranked results of the solutions afer removing *A5* solution

The results in Fig. 3 also show that there is not any rank inversion phenomenon in all the solutions. Again, the *CURLI* method is determined to be very successful in this example.

Three above examples were mentioned to select materials in three different fields with different number of solutions, different number of criteria. However, when using the *CURLI* method to rank solutions, the best determined solution was always similar to that one when using other *MCDM* methods. The stability analysis of the ranking results of the solutions in the three examples was also conducted with three different scenarios (case 1: removing the best solution, case 2: removing the worst solution, and case 3: removing any solution). However, in all three cases, no ranking reversion phenomenon was detected. These results are sufficient to confirm that when using the *CURLI* method to find the best solution, it is completely correct, and addition, it is also confirmed that the ranking inversion phenomenon does not occur when using the *CURLI* method.

5. CONCLUSION

Selecting the suitable material is important for machining processes. Multi-criteria decision making that is a technique commonly used to solve the problems in these situations. Difficulties in choosing the method of data normalization as well as the determination method of the criterion weight will not be encountered if using the *CURLI* method. This study used the *CURLI* method to rank the materials in three different fields. Some conclusions are drawn as follows:

- ✓ The best solution that was found when using the *CURL*I method is always similar to that one when using other well-known and widely used methods such as *EDAS*, *PROMETHEE*, *EXPROM2*, *TOPSIS*, and *VIKOR*;
- ✓ The strength of the *CURLI* method was also found that the ranking inversion phenomenon does not occur under any scenarios. This is the advantage of the *CURLI* method in comparing with many other methods. Moreover, when applied the *CURLI* method, it does not require the determining weights for the criteria nor require the normalizing the data, so, it is recommended to be used;
- ✓ The application of the *CURLI* method to rank the solutions in other fields is also expected to be successful. Further studies are needed to verify this this comment;
- ✓ In this study as well as in published studies, the CURLI method is only used to rank the solutions when the value of each criterion at each solution is a unique quantity. Using this method to rank the solutions when the certain criterion that is presented as a fuzzy set is also a further research direction of this study.

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