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APPLYING MULTI-CRITERIA DECISION-MAKING METHODS FOR CUTTING OIL SELECTION

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Many machining processes would not be possible without the presence of cutting oils. There are many different types of cutting oils on the market today, each with different properties. The difference of oils is manifested in many parameters such as viscosity, combustion temperature, recyclability, pollution tendency, stability, price, etc. Choosing the best oil is a difficult and tedious task for customers. In this work, we present the results of a study on the selection of cutting oil using multi-criteria decision-making (MCDM) methods. The selection of the best oil is made on the basis of ranking of seven different types. Two MCDM methods used in this study are Proximity Indexed Value (PIV) and Collaborative Unbiased Rank List Integration (CURLI). This two methods have been used to rank cutting oils. These are two methods with completely different characteristics. When using the PIV method, it is necessary to standardize the data and determine the weights for the criteria. Meanwhile, if using the CURLI method, these two tasks are not needed. In addition, three different weight methods were also used to calculate the weights for the criteria including EQUAL, Rank Order Centroid weight (ROC weight) and Rank Sum weight (RS weight). These three methods have been used to determine the weights for the criteria of cutting oil. The PIV method was used three times corresponding to three different weight methods. The results showed that out of the four ranking results (three using the PIV method and one using the CURLI method), the same best oil was unanimously identified. It is recommended that the CURLI method should be used if weighting of criteria and data normalization are not desired

Keywords: cutting oil, MCDM methods, CURLI method, PIV method, weight method

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1. Introduction

Cutting oil is a crucial ingredient in cutting processes. Both the cutting tool components and the workpiece will be damaged rapidly if the machining process does not use cutting oil. Rapid damage to the cutting tool and the workpiece is due to the heat generated in the cutting area. Cutting oil has a cooling effect on both the cutting tool and the workpiece, so that the machining process is carried out continuously and the necessary requirements are ensured. In addition, cutting oil also lubricates the surfaces of the cutting tool and the workpiece. This effect of cutting oil also plays a very important role in improving tool life and ensuring machining accuracy. However, there are many different types of cutting oils on the market, making it impossible for customers to choose the best one based on their subjective opinion. This difficulty comes from the fact that each type of cutting oil has many different parameters such as kinematic viscosity, combustion temperature, freezing point, price, etc. It is necessary to choose an oil ensuring that all of these parameters are considered «best». Therefore, the selection of cutting oil using a multi-criteria decision-making method is necessary.

2. Literature review and problem statement

MCDM methods have been used successfully in ranking alternatives in many different fields [1]. In the selection of cutting oil, some MCDM methods have also been applied. In [2], the PSI method was used to rank four different oils. Eight criteria were used to describe each oil including Wheel wear (*C*1), Tangential force (*C*2), Grinding temperature (*C*3), Surface roughness (*C*4), Recyclability (*C*5), Toxic harm rate (*C*6), Environment pollution tendency (*C*7), and Stability (*C*8). In which, the criteria *C*1–*C*4 and *C*8 are as large as possible. In contrast, *C*6 and *C*7 are the two criteria that are as small as possible. The study has identified an oil simultaneously ensuring that *C*1–*C*4 and *C*8 are considered to be the largest and *C*6 and *C*7 are considered to be the smallest. In [3], the ROV method was used to rank four different oils. Eight parameters including Wheel wear (*C*1), Tangential force (*C*2), Grinding temperature (*C*3), Surface roughness (*C*4), Recyclability (*C*5), Toxic harm rate (*C*6), Environment pollution tendency (*C*7), and Stability (*C*8) were used as assessment criteria for each alternative. In which, only *C*6 and *C*7 are the criteria that are as small as possible, and the remaining criteria are as large as possible. This study has found an oil simultaneously ensuring that the two criteria $C6$ and $C7$ are considered to be the smallest, and the remaining criteria are considered to be the largest. In [4], the VIKOR method was used to rank three different oils. Lubricating ability ($C1$), Cooling ability ($C2$), Cleaning ability ($C3$), Corrosion resistance ($C4$), Toxicity ($C5$), Security ($C6$), Environmental pollution ($C7$), Enterprise cost ($C8$), Consumer cost ($C9$), Social cost ($C10$) are the ten criteria used to assess each alternative. In which, the five criteria including $C1$–$C4$ and $C6$ are as large as possible, and the five remaining criteria are as small as possible. This study has identified an alternative simultaneously ensuring that all five criteria $C1$–$C4$ and $C6$ are considered to be the largest and all five remaining criteria are considered to be the smallest. In [5], the TOPSIS method was used to rank six different cutting oils. Surface roughness ($C1$), energy consumption ($C2$) and tool wear ($C3$) were the three criteria used for the assessment of each alternative. All three of these criteria are as small as possible. This study has identified an oil simultaneously ensuring that all three criteria are considered to be the smallest. In [6], the AHP method was used to rank three different oils. Environmental impact ($C1$), Cost ($C2$), and Qualities ($C3$) are the three criteria used for the assessment of each oil. In which, $C3$ is the criterion that is as large as possible, and the other two criteria are as small as possible. This study has identified an oil, for which $C1$ and $C2$ are considered to be the smallest and $C3$ is considered to be the largest. In [7], the two methods COPRAS and ARAS were used simultaneously to rank three cutting oils. Each cutting oil is characterized by ten criteria including Lubricating ability ($C1$), Cooling ability ($C2$), Cleaning ability ($C3$), Corrosion resistance ($C4$), Toxicity harm ($C5$), Insecurity ($C6$), Environmental pollution ($C7$), Enterprise cost ($C8$), Consumer cost ($C9$), and Social cost ($C10$). In which, the first seven criteria are as large as possible, whereas the last three criateria are as small as possible. This study has found an oil simultaneously ensuring that the first seven criteria are considered to be the largest and the last three criteria are considered to be the smallest. In [8], the three MCDM methods were used to rank four different oils. The three used methods include: VIKOR, PROMETHEE, and ELECTRE. Eight criteria were used to describe each oil: Tangential force ($C1$), Surface roughness ($C2$), Wheel wear ($C3$), Grinding temperature ($C4$), Recyclability ($C5$), Toxic harm rate ($C6$), Environment pollution tendency ($C7$), and Stability ($C8$). The criteria $C1$, $C2$, $C3$, $C4$, $C5$ and $C8$ are as large as possible, meanwhile the remaining two criteria are as small as possible. The results showed that all three methods VIKOR, PROMETHEE and ELECTRE have identified the same best oil. In [9], the three methods including MOOSRA, DMF and AHP were used simultaneously to rank three different cutting oils. Ten criteria were used to describe each oil including Lubricating ability ($C1$), Cooling ability ($C2$), Cleaning ability ($C3$), Corrosion resistance ($C4$), Toxicity ($C5$), Security ($C6$), Environmental pollution ($C7$), Enterprise cost ($C8$), Consumer cost ($C9$), and Social cost ($C10$). In which, the four criteria $C5$, $C8$–$C10$ are as small as possible, meanwhile the remaining six criteria are as large as possible. This study has shown that all three methods MOOSRA, DMF and AHP have identified the same best alternative, which is the one simultaneously ensuring that the four criteria $C5$, $C8$–$C10$ are considered to be the smallest and the remaining six criteria are considered to be the largest. Thus, it can be said that MCDM methods have been used quite a lot for multi-criteria decision-making in the selection of cutting oils. However, all of the studies listed above have not considered the criteria of the kinetic and thermodynamic properties of oil such as kinematic viscosity, minimum value of viscosity, minimum temperature value of flash point, freezing point, etc. These are extremely important parameters that must be considered when choosing a cutting oil. This gap will be filled in this study.

PIV and CURLI are also well-known MCDM methods and have been applied to multi-criteria decision-making in many different fields. In a short time, there have been recently many studies applying the PIV method for multi-criteria decision-making for the turning process [10, 11], milling process [12], grinding process [13], etc. The CURLI method has also been applied to multi-criteria decision-making in many cases such as: ranking of seven types of robots, ranking of nine turning processes and ranking of six bridge construction alternatives [14]; ranking of five types of protective plate materials for automobiles, ranking of nine types of gear materials, and ranking of twelve types of cutting tool materials [15]; ranking of woodworking machines [16]; ranking of eight types of grinding wheels and ranking of three types of logistics services [17], etc. However, the authors of this paper can confirm that both the PIV and CURLI methods have never been used to rank cutting oils. This is the motivation for doing this study. On the other hand, there is a big difference between the PIV method and the CURLI method. Such a difference is that when using the PIV method, it is necessary to normalize the data and determine the weights for the criteria, while it is not necessary to perform these two tasks when using the CURLI method. The difference between PIV and CURLI is also the reason that they were chosen for use in this study. Besides, when using the PIV method, it is necessary to calculate the weights for the criteria. However, the alternative ranking results are highly dependent on the weight method [18]. Therefore, in order to confirm with confidence that a certain alternative is truly the best, it is required to rank the alternatives with many different weight methods.

3. The aim and objectives of the study

The aim of this study was to apply multi-criteria decision-making (MCDM) methods to select cutting oils.

To achieve this aim, the following objectives are accomplished:

– to solve the MCDM problem to find the best cutting oil using the PIV method with three weight methods;

– to solve the MCDM problem to find the best cutting oil using the CURLI method.

4. Materials and methods

4. 1. Object of the study

The research object is methods of determining weights and methods of multi-criteria decision-making. Specifically, the three weighting methods mentioned in this study include the EQUAL weight method, the ROC (Rank Order Centroid) weight method and the RS (Rank Sum) weight method. PIV (Proximity Indexed Value) and CURLI (Collaborative Unbiased Rank List Integration) are two multi-criteria decision-making methods that were used in this study.

4. 2. Weight methods used

The EQUAL weight method is used to calculate the weights of the criteria in accordance with (1) [19]:

$$w_j = \frac{1}{n} \text{ with } j = 1 \div n, \quad (1)$$

where n is the number of criteria, w_j is the weight of the j-th criterion.

The ROC (Rank Order Centroid) weight method is used to calculate the weights of the criteria in accordance with (2) [19]:

$$w_j = \frac{1}{n}\sum_{k=1}^{n}\frac{1}{k}. \quad (2)$$

The formula (3) is used to calculate the weights of the criteria in accordance with the RS (Rank Sum) weight method [19]:

$$w_j = \frac{2(n+1-i)}{n(n+1)}. \quad (3)$$

The above formulas are used to calculate the weights of the criteria of cutting oil in the next part of this paper.

4. 3. Multi-Criteria Decision-Making methods used

4. 3. 1. Proximity Indexed Value method

The PIV (Proximity Indexed Value) method ranks the alternatives in the following order [20]:

Step 1. Build a decision-making matrix with m alternatives and n criteria.

Calculate the normalized values in accordance with (4):

$$n_{ij} = \frac{y_{ij}}{\sqrt{\sum_{i=1}^{m} y_{ij}^2}}, \quad (4)$$

where y_{ij} is the value of the j-th criterion in alternative I, $i=1\div m, j=1\div n$.

Step 2. Calculate the normalized values taking into account the weights of the criteria in accordance with (5):

$$\nu_{ij} = w_j \times n_{ij}, \quad (5)$$

where w_j is the weight of the j-th criterion.

Step 3. Calculate the asymptotic indexes in accordance with the two formulas (6) and (7).

– for the as-large-as-possible criteria:

$$u_i = \nu_{max} - \nu_i; \quad (6)$$

– for the as-small-as-possible criteria:

$$u_i = \nu_i - \nu_{min}. \quad (7)$$

Step 4. Determine the overall neighborhood value in accordance with the formula (8):

$$d_i = \sum_{j=1}^{n} u_i. \quad (8)$$

Step 5. Rank the alternatives by the principle that the best alternative is the one with the smallest d_i.

4. 3. 2. Collaborative Unbiased Rank List Integration method

The CURLI (Collaborative Unbiased Rank List Integration) method was used to rank the alternatives in the following order [21]:

Step 1. Build a decision-making matrix (similar to Step 1 of the PIV method).

Step 2. Score the alternatives for each criterion. The scoring result of each criterion is a square matrix of level m. So, with n criteria, we will have n scoring matrices. The scoring principle is as follows: for example, in the cell corresponding to column 1 and row 2, if the value of criterion $C1$ of $A1$ is better than that of $A2$, then score 1 in such cell; or in the cell corresponding to column 2 and row 1, if the value of criterion $C2$ of $A2$ is worse than that of $A1$, then score –1 in such cell; or in the cell corresponding to column 2 and row m, if the value of criterion $C2$ of $A2$ is equal to that of A_m, then score 0 in such cell; in the cells where the row number is the same as the column number, for example, cell 1–1, cell 2–2, ... cell m–m (the cells on the main diagonal of the matrix), we score 0. We call this matrix a scoring matrix for each criterion (Table 1).

Table 1

Example of scoring matrix for each criterion

No.	P_1	P_2	...	P_m
A_1	0	–1	...	...
A_2	1	0	...	...
...	...	...	0	...
A_m	...	0	...	0

Step 3. Add all scoring matrices for each criterion together, to get a matrix called the process scoring matrix.

Step 4. Sort the process scoring matrix by changing the positions of rows and columns to form a matrix where the number of cells with negative values above the main diagonal is the maximum (the number of cells with positive values below the main diagonal is the maximum). After sorting, the alternative ranked in row 1 is considered the best one.

5. Results of cutting oil selection

5. 1. Selection of the best cutting oil using the Proximity Indexed Value method

Seven cutting oils were reviewed for ranking in this study. These are the seven most popular oils on the Vietnamese market. They are respectively denoted by the letters $CO1$, $CO2$, ... $CO7$. Six criteria were used to assess each oil, including: Kinematic viscosity ($C1$), Minimum value of viscosity ($C2$), Minimum temperature value of flash point ($C3$), Freezing point ($C4$), pH when diluted with a concentration of 5 % ($C5$), Price ($C6$). Five criteria from $C1$ to $C5$ have not been considered in previous studies when selecting cutting oils. This is the first time they are mentioned. In which, $C1$, $C2$, $C3$ and $C4$ criteria are as large as possible. The remaining two criteria ($C5$ and $C6$) are as small as possible. Data for the seven oils are summarized in Table 2.

Table 2

Criteria of cutting oils

No.	$C1$	$C2$	$C3$	$C4$	$C5$	$C6$
$CO1$	40	90	150	6	9.25	2.84
$CO2$	38	85	160	8	11.22	2.72
$CO3$	38	90	160	8	9.36	2.96
$CO4$	42	92	200	6	8.52	3.02
$CO5$	40	96	210	5	7.42	3.22
$CO6$	38	75	180	6	7.26	3.12
$CO7$	39	88	190	6	7.26	3.16

Equations (1), (2) and (3) were applied to calculate the weights of the criteria using three different methods. The results are summarized in Table 3.

Table 3

Weights of criteria

Weight method	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6
EQUAL	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667
ROC	0.4083	0.2417	0.1583	0.1028	0.0611	0.0278
RS	0.2857	0.2381	0.1905	0.1429	0.0952	0.0476

Five steps of PIV were applied to the ranking of oils.

The main decision-making matrix is the data table of oils (Table 3).

The normalized values are calculated in accordance with the equation (4), with the results shown in Table 4.

The weighted normalized value is calculated in accordance with the equation (5). First, we apply to the case that the weights of the criteria are calculated by the EQUAL weight method. The calculation results are summarized in Table 5.

The asymptotic indexes are calculated in accordance with the two equations (6) and (7), the results are summarized in Table 6.

Table 4

Normalized values of criteria

No.	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6
*CO*1	0.3846	0.3856	0.3153	0.3482	0.4010	0.3566
*CO*2	0.3654	0.3642	0.3363	0.4642	0.4864	0.3415
*CO*3	0.3654	0.3856	0.3363	0.4642	0.4058	0.3716
*CO*4	0.4038	0.3942	0.4204	0.3482	0.3693	0.3792
*CO*5	0.3846	0.4113	0.4414	0.2901	0.3217	0.4043
*CO*6	0.3654	0.3213	0.3784	0.3482	0.3147	0.3917
*CO*7	0.3750	0.3770	0.3994	0.3482	0.3147	0.3968

Table 5

Weighted normalized values of criteria

No.	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6
*CO*1	0.0641	0.0643	0.0526	0.0580	0.0668	0.0594
*CO*2	0.0609	0.0607	0.0561	0.0774	0.0811	0.0569
*CO*3	0.0609	0.0643	0.0561	0.0774	0.0676	0.0619
*CO*4	0.0673	0.0657	0.0701	0.0580	0.0616	0.0632
*CO*5	0.0641	0.0686	0.0736	0.0484	0.0536	0.0674
*CO*6	0.0609	0.0536	0.0631	0.0580	0.0525	0.0653
*CO*7	0.0625	0.0628	0.0666	0.0580	0.0525	0.0661

Table 6

Asymptotic indexes

No.	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6
*CO*1	0.0032	0.0043	0.0210	0.0193	0.0144	0.0025
*CO*2	0.0064	0.0079	0.0175	0.0000	0.0286	0.0000
*CO*3	0.0064	0.0043	0.0175	0.0000	0.0152	0.0050
*CO*4	0.0000	0.0029	0.0035	0.0193	0.0091	0.0063
*CO*5	0.0032	0.0000	0.0000	0.0290	0.0012	0.0105
*CO*6	0.0064	0.0150	0.0105	0.0193	0.0000	0.0084
*CO*7	0.0048	0.0057	0.0070	0.0193	0.0000	0.0092

The overall neighborhood value (d_i) of the alternatives is calculated in accordance with the equation (9), the results are summarized in Table 7. The results of ranking of alternatives are also summarized in Table 7.

Table 7

Overall neighborhood values of alternatives and ranking of alternatives

No.	d_i	Rank
*CO*1	0.0647	7
*CO*2	0.0604	6
*CO*3	0.0484	4
*CO*4	0.0411	1
*CO*5	0.0438	2
*CO*6	0.0596	5
*CO*7	0.0461	3

Thus, the ranking of alternatives when the weights of the criteria are calculated by the EQUAL weight method has been completed. The ranking of alternatives when the weights of the criteria are calculated by other alternatives is also similarly made. Table 8 shows the summary results of ranking oils corresponding to the three different weight methods.

Table 8

Results of ranking oils by the PIV method

No.	Weight method		
	EQUAL	ROC	RS
*CO*1	7	5	6
*CO*2	6	6	5
*CO*3	4	4	4
*CO*4	1	1	1
*CO*5	2	2	2
*CO*6	5	7	7
*CO*7	3	3	3

Thus, the ranking of cutting oils by the PIV method has ended. Accordingly, for all three weighting methods used including EQUAL weight, ROC weight and RS weight, *CO*4 is always determined to be the best cutting oil, *CO*5 ranks second, *CO*7 ranks third, and *CO*3 ranks fourth. The best solution is determined regardless of the weighting method used.

5. 2. Selection of the best cutting oil using the Collaborative Unbiased Rank List Integration method

The steps to rank alternatives using the CURLI method are applied as follows.

The results of scoring alternatives for the criterion *C*1 are shown in Table 9.

Table 9

Scoring matrix for criterion *C*1

No.	Score						
	S_1	S_2	S_3	S_4	S_5	S_6	S_7
*CO*1	0	–1	–1	1	0	–1	–1
*CO*2	1	0	0	1	1	0	1
*CO*3	1	0	0	1	1	0	1
*CO*4	–1	–1	–1	0	–1	–1	–1
*CO*5	0	–1	–1	1	0	–1	–1
*CO*6	1	0	0	1	1	0	1
*CO*7	1	–1	–1	1	1	–1	0

The results of scoring alternatives for the criterion *C*2 are shown in Table 10.

Table 10

Scoring matrix for criterion *C*2

No.	Score						
	S_1	S_2	S_3	S_4	S_5	S_6	S_7
*CO*1	0	–1	0	1	1	–1	–1
*CO*2	1	0	1	1	1	–1	1
*CO*3	0	–1	0	1	1	–1	–1
*CO*4	–1	–1	–1	0	1	–1	–1
*CO*5	–1	–1	–1	–1	0	–1	–1
*CO*6	1	1	1	1	1	0	1
*CO*7	1	–1	1	1	1	–1	0

The results of scoring alternatives for the criterion *C*3 are shown in Table 11.

Table 11

Scoring matrix for criterion *C*3

No.	Score						
	S_1	S_2	S_3	S_4	S_5	S_6	S_7
*CO*1	0	1	1	1	1	1	1
*CO*2	–1	0	0	1	1	1	1
*CO*3	–1	0	0	1	1	1	1
*CO*4	–1	–1	–1	0	1	–1	–1
*CO*5	–1	–1	–1	–1	0	–1	–1
*CO*6	–1	–1	–1	1	1	0	1
*CO*7	–1	–1	–1	1	1	–1	0

The results of scoring alternatives for the criterion *C*4 are shown in Table 12.

Table 12

Scoring matrix for criterion *C*4

No.	Score						
	S_1	S_2	S_3	S_4	S_5	S_6	S_7
*CO*1	0	1	1	0	–1	0	0
*CO*2	–1	0	0	–1	–1	–1	–1
*CO*3	–1	0	0	–1	–1	–1	–1
*CO*4	0	1	1	0	–1	0	0
*CO*5	1	1	1	1	0	1	1
*CO*6	0	1	1	0	–1	0	0
*CO*7	0	1	1	0	–1	0	0

The results of scoring alternatives for the criterion *C*5 are shown in Table 13.

Table 13

Scoring matrix for criterion *C*5

No.	Score						
	S_1	S_2	S_3	S_4	S_5	S_6	S_7
*CO*1	0	–1	–1	1	1	1	1
*CO*2	1	0	1	1	1	1	1
*CO*3	1	–1	0	1	1	1	1
*CO*4	–1	–1	–1	0	1	1	1
*CO*5	–1	–1	–1	–1	0	1	1
*CO*6	–1	–1	–1	–1	–1	0	0
*CO*7	–1	–1	–1	–1	–1	0	0

The results of scoring alternatives for the criterion *C*6 are shown in Table 14.

Table 14

Scoring matrix for criterion *C*6

No.	Score						
	S_1	S_2	S_3	S_4	S_5	S_6	S_7
*CO*1	0	1	–1	–1	–1	–1	–1
*CO*2	–1	0	–1	–1	–1	–1	–1
*CO*3	1	1	0	–1	–1	–1	–1
*CO*4	1	1	1	0	–1	–1	–1
*CO*5	1	1	1	1	0	1	1
*CO*6	1	1	1	1	–1	0	–1
*CO*7	1	1	1	1	–1	1	0

The process scoring matrix is shown in Table 15.

Table 15

Process scoring matrix

No.	Score						
	S_1	S_2	S_3	S_4	S_5	S_6	S_7
*CO*1	0	0	–1	3	1	–1	–1
*CO*2	0	0	1	2	2	–1	2
*CO*3	1	–1	0	2	2	–1	0
*CO*4	–3	–2	–2	0	0	–3	–3
*CO*5	–1	–2	–2	0	0	0	0
*CO*6	1	1	1	3	0	0	2
*CO*7	1	–2	0	3	0	–2	0

The positions of rows and columns of the process scoring matrix are arranged so that the number of cells with negative values above the main diagonal is the maximum. We get the results as shown in Table 16.

Table 16

Process scoring matrix after rearranging positions of rows and columns

No.	Score						
	S_4	S_5	S_7	S_1	S_3	S_2	S_6
*CO*1	0	0	–3	–3	–2	–2	–3
*CO*2	0	0	0	–1	–2	–2	0
*CO*3	3	0	0	1	0	–2	–2
*CO*4	3	1	–1	0	–1	0	–1
*CO*5	2	2	0	1	0	–1	–1
*CO*6	2	2	2	0	1	0	–1
*CO*7	3	0	2	1	1	1	0

In accordance with the data in Table 16, the results of ranking of oils are as follows: *CO*4>*CO*5>*CO*7>*CO*1>*CO*3>>*CO*2>*CO*6. Accordingly, *CO*4 is the best cutting oil.

Fig. 1 shows a chart comparing the results of ranking of oils by different methods. This chart is built according to the data of Table 8 and Table 16.

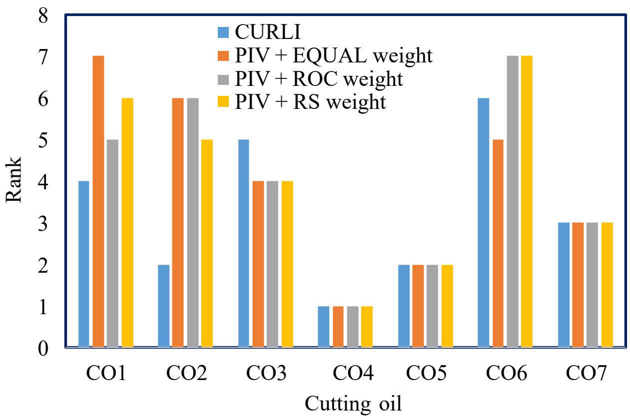

Fig. 1. Ranking of cutting oils

A discussion of the results of ranking oils by different methods is presented in the next part of this study.

6. Discussion of the results of multi-criteria decision-making

From Fig. 1, it can be seen that:

The results of ranking of alternatives by different methods are not exactly the same. This is also completely understandable since three different methods of determining weights have been used. In addition, when using the PIV method, it is necessary to consider the weights of the criteria, and when using the CURLI method, it is not necessary to do so. This is also consistent with the claims in many published literature [22].

The best alternative is determined by the PIV method regardless of the weights of the criteria (at least in the ranking of cutting oils). This confirms the superiority of the PIV method over most other MCDM methods. That advantage is the reduction of rank inversion, as claimed earlier [20]. Both PIV and CURLI methods determine *CO4* as the best cutting oil. That creates a certain confidence when using these two methods in multi-criteria decision-making.

The limitation of this study is that it did not consider other cutting oil criteria such as degree of environmental hazard, degree of toxicity to the machine operator, quality of the workpiece, etc.

The disadvantage of this study is that when determining the weights of the criteria, the decision maker's point of view is not taken into account. When the decision maker's point of view needs to be considered, the AHP (Analytic Hierarchy Process) approach can be used [23].

The use of oils in the production process to assess the actual efficiency of the machining process is also the task to be performed in further studies. At that time, the measurement of many parameters needs to be performed to evaluate the efficiency of the machining process.

7. Conclusions

1. When using the PIV method to rank alternatives, it is always possible to determine the same best solution, regardless of the weights of the criteria. Accordingly, when using three different weighting methods (including EQUAL weight, ROC weight and RS weight), the ranking results of oils are completely identical in 4/7 options. *CO4* is always ranked first, *CO5* is always ranked second, *CO3* is always ranked third, and *CO7* is always ranked fourth.

2. When using the CURLI method, it was also determined that *CO4* was the best type. It is recommended that the CURLI method should be used if weighting of criteria and data normalization are not desired. The best oil is the one with a kinematic viscosity of 40, minimum value of viscosity of 96, minimum temperature of flash point of 210 °C, freezing point of 5 °C, pH when diluted with a concentration of 8.52, and price of 3.02 (USD/litre).

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Data availability

The manuscript has data included as electronic supplementary material.

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References

1. Nguyen, H. S., Vo, N. U. T. (2022). Multi-Objective Optimization in Turning Process Using RIM Method. Applied Engineering Letters: Journal of Engineering and Applied Sciences, 7 (4), 143–153. doi: https://doi.org/10.18485/aeletters.2022.7.4.2
2. Petković, D., Madić, M., Radovanović, M., Gečevska, V. (2017). Application of the performance selection index method for solving machining mcdm problems. Facta Universitatis, Series: Mechanical Engineering, 15 (1), 97. doi: https://doi.org/10.22190/fume151120001p
3. Madić, M., Radovanović, M., Manić, M. (2016). Application of the ROV method for the selection of cutting fluids. Decision Science Letters, 245–254. doi: https://doi.org/10.5267/j.dsl.2015.12.001
4. Jagadish, Ray, A. (2014). Cutting Fluid Selection for Sustainable Design for Manufacturing: An Integrated Theory. Procedia Materials Science, 6, 450–459. doi: https://doi.org/10.1016/j.mspro.2014.07.058
5. Sen, B., Gupta, M., Mia, M., Pimenov, D., Mikołajczyk, T. (2021). Performance Assessment of Minimum Quantity Castor-Palm Oil Mixtures in Hard-Milling Operation. Materials, 14 (1), 198. doi: https://doi.org/10.3390/ma14010198

6. Deshamukhya, T., Ray, A. (2014). Selection of cutting fluid for greenmanufacturing using Analytical Hierarchy Process (AHP): A CASE STUDY. International Journal of Mechanical Engineering and Robotics Research, 3 (1), 173–182. Available at: http://www.ijmerr.com/v3n1/ijmerr_v3n1_20.pdf
7. Goswami, S. S., Behera, D. K. (2021). Implementation of COPRAS and ARAS MCDM Approach for the Proper Selection of Green Cutting Fluid. Current Advances in Mechanical Engineering, 975–987. doi: https://doi.org/10.1007/978-981-33-4795-3_90
8. Jayant, A., Neeru, Singh, P. (2018). A decision-making framework model of cutting fluid selection for green manufacturing: A synthesis of 3 MCDM approaches, 2018, 1st International Conference on Advances in Engineering and Technology. Quetta. Available at: https://www.researchgate.net/publication/323748301_A_DECISION-MAKING_FRAMEWORK_MODEL_OF_CUTTING_FLUID_SELECTION_FOR_GREEN_MANUFACTURING_A_SYNTHESIS_OF_3_MCDM_APPROACHES
9. Jagadish, Ray, A. (2014). Green cutting fluid selection using moosra method. International Journal of Research in Engineering and Technology, 03 (03), 559–563. doi: https://doi.org/10.15623/ijret.2014.0315105
10. Duc Trung, D. (2021). A combination method for multi-criteria decision making problem in turning process. Manufacturing Review, 8, 26. doi: https://doi.org/10.1051/mfreview/2021024
11. Trung, D. D. (2021). Application of EDAS, MARCOS, TOPSIS, MOORA and PIV Methods for Multi-Criteria Decision Making in Milling Process. Strojnícky Časopis – Journal of Mechanical Engineering, 71 (2), 69–84. doi: https://doi.org/10.2478/scjme-2021-0019
12. Do, T. (2021). The Combination of Taguchi – Entropy – WASPAS-PIV Methods for Multi-Criteria Decision Making when External Cylindrical Grinding of 65G Steel. Journal of Machine Engineering, 21 (4), 90–105. doi: https://doi.org/10.36897/jme/144260
13. Do, T. (2021). Application of TOPSIS an PIV Methods for Multi-Criteria Decision Making in Hard Turning Process. Journal of Machine Engineering, 21 (4), 57–71. doi: https://doi.org/10.36897/jme/142599
14. Trung, D. D. (2022). Comparison R and CURLI methods for multi-criteria decision making. Advanced Engineering Letters, 1 (2), 46–56. doi: https://doi.org/10.46793/adeletters.2022.1.2.3
15. Tran, D. V. (2022). Application of the Collaborative Unbiased Rank List Integration Method to Select the Materials. Applied Engineering Letters: Journal of Engineering and Applied Sciences, 7 (4), 133–142. doi: https://doi.org/10.18485/aeletters.2022.7.4.1
16. Dua, T. V. (2023). Combination of symmetry point of criterion, compromise ranking of alternatives from distance to ideal solution and collaborative unbiased rank list integration methods for woodworking machinery selection for small business in Vietnam. EUREKA: Physics and Engineering, 2, 83–96. doi: https://doi.org/10.21303/2461-4262.2023.002763
17. Nguyen, A.-T. (2023). The Improved CURLI Method for Multi-Criteria Decision Making. Engineering, Technology & Applied Science Research, 13 (1), 10121–10127. doi: https://doi.org/10.48084/etasr.5538
18. Dung, H. T., Do, D. T., Nguyen, V. T. (2022). Comparison of Multi-Criteria Decision Making Methods Using The Same Data Standardization Method. Strojnícky Časopis – Journal of Mechanical Engineering, 72 (2), 57–72. doi: https://doi.org/10.2478/scjme-2022-0016
19. Son, N. H., Hieu, T. T. (2023). Selection of welding robot by multi-criteria decision-making method. Eastern-European Journal of Enterprise Technologies, 1 (3 (121)), 66–72. doi: https://doi.org/10.15587/1729-4061.2023.269026
20. Mufazzal, S., Muzakkir, S. M. (2018). A new multi-criterion decision making (MCDM) method based on proximity indexed value for minimizing rank reversals. Computers & Industrial Engineering, 119, 427–438. doi: https://doi.org/10.1016/j.cie.2018.03.045
21. Kiger, J. R., Annibale, D. J. (2016). A new method for group decision making and its application in medical trainee selection. Medical Education, 50 (10), 1045–1053. doi: https://doi.org/10.1111/medu.13112
22. Trung, D. D. (2022). Development of data normalization methods for multi-criteria decision making: applying for MARCOS method. Manufacturing Review, 9, 22. doi: https://doi.org/10.1051/mfreview/2022019
23. Podvezko, V. (2009). Application of AHP Technique. Journal of Business Economics and Management, 10 (2), 181–189. doi: https://doi.org/10.3846/1611-1699.2009.10.181-189