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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

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Abstract

Woodworking industry plays an important role in the development of Vietnam's economy. The efficiency of woodworking process depends a lot on the machinery used in the woodworking process. Selecting the best option among a variety of machines is tedious and complex work. However, if the choice of machine is based only on the subjective opinion of the customer, it will lead to mistakes. That mistake is understood that the customer will choose the option that is not the best among the machines proposed by the supplier. Instead, machine selection must be based on all machine parameters. This is called multi-criteria decision making (MCDM). There are MCDM methods, when used it is necessary to know the weights of the criteria. However, there are also methods that do not need to know the weights of the criteria. CRADIS (Compromise Ranking of Alternatives from Distance to Ideal Solution) is a method that, when used, is required to weight the criteria. In contrast, this problem is unnecessary when using the CURLI (Collaborative Unbiased Rank List Integration) method. In this study, three kinds of machinery commonly used for small business in woodworking field were selected. The three kinds of machinery mentioned in this study include wood milling machine, wood saw machine, wood planer. The *SPC* (Symmetry Point of Criterion) method was used to calculate the weights of the criteria for each kind of machinery. This is the youngest method among the methods of determining the weights for the criteria, it was only found in 2023. The two methods include *CRADIS* and *CURLI* were used to rank the machinery kinds. The result showed that in all the surveyed situation, the best alternative is always determined consistently when using CRADIS and CURLI methods. Accordingly, three best alternatives with three different machinery kinds (milling machine, saw machine and planer) were found in this study.

Keywords: MCDM, SPC method, CRADIS method, CURLI method, wood working machinery.

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1. Introduction

The income from wood industry plays an important role in Vietnam's economy. Vietnam is the largest wood exporter in Southeast Asia, and the second largest in Asia. Worldwide, Vietnam is the sixth largest wood exporter. According to the Vietnam Customs Department, in 2022, the export turnover of wood products reached over 11 billion USD [1]. The wood products which are exported from Vietnam include furniture, wood chips, pallets, peeled boards, particle boards, fiber boards. According to the Vietnam Economic Times, the Vietnam government has the policies to promote the development of wood industry, aiming for a turnover of 16 billion USD by 2023 [2]. The income of small business in woodworking field accounts for a very high proportion of the total export turnover of wood products of Vietnam.

The efficiency of processing wood products is influenced by many factors. In which the kinds of machinery used for woodworking play an important role. The work of selecting machinery for woodworking affects many factors such as productivity, safety in use, energy consumption, environmental impact, machinery cost, etc. [3]. Woodworking equipment kinds are used in all sizes of production, from small businesses to large and huge companies. Many kinds of machinery are necessary for woodworking process such as milling machine, saw machine, planers, chisel, sandblasting machine, drilling machine, edge banding machine. For small businesses, three kinds of machinery that are most commonly used wood milling machine, wood saw machine and wood planer. However, choosing the suiTable woodworking machinery is very complicated because many factors (criteria) need to be considered. All the customers want to choose a product with both good quality, high productivity but also low price. However, in reality, things like this rarely happen because a machine with high productivity will also cost a lot, and vice versa [4, 5].

Choosing a product while considering the harmonization of criteria is known as a multi-criteria decision-making (*MCDM*). Hundreds of different *MCDM* methods were proposed by scientists, and to apply them in so many different fields [6, 7]. However, in this field, only a few of them are published to select wood working machinery. The *AHP* method was used to select woodworking CNC machines [8]. The fuzzy-*AHP* method was also used to select CNC routers [9]. Therefore, the application of *MCDM* methods for multi-criteria decision-making in the selection of woodworking machinery will contribute useful documents to the current research direction. This is the first reason why this study was conducted.

When applying almost every *MCDM* methods, it is a need to determine the weights of the criteria [10]. At present, there are many different methods to determine the weights proposed by researchers. For each specific case, the weights of the criteria could be different if they are determined by different weighting methods. Then, the result of ranking the alternatives could also be different [11]. *SPC* is a method for determining the weights of the criteria proposed recently, it was found in January, 2023 [12]. Because it has just appeared in a very short time, so, up to present, there has not been a single study, which has applied this method to determine the weights of the criteria. This gap is the second reason for this study to apply this method (*SPC* method) in determining the weights of the criteria of woodworking machines.

As mentioned above, at present, hundreds of different *MCDM* methods were proposed by scientists. However, it seems to be no concept of a method being better than another, it can only be said that a method is suiTable or unsuiTable when it is applied in a certain situation [13, 14].

CRADIS is a multi-criteria decision-making method that was made by the combination of *ARAS* method, *MARCOS* method and *TOPSIS* method. It was found in 2022 when ranking medical waste incinerators. It has shown the outstanding advantage in minimizing the rank reversals [15]. Although it was found in a very short time, this method was applied by some scientists for ranking the alternatives in some studies: ranking agricultural machines [16], assessing the impact of FDI (Foreign Direct Investments) to the sustainability of the economic system [17], ranking forty-six countries based on three alternatives include energy, environment and sustainability [18], evaluating the global innovation index of the countries from the Western Balkans [19]. This method was also improved into fuzzy *CRADIS* method for ranking types of pear in Serbia [20], and selecting green suppliers [21]. So, it can be said that although it was found recently but the *CRADIS* method have attracted the attention of researchers to rank the alternatives in many different fields. The application of the *CRADIS* method to rank and select woodworking machinery is a new point that is done in this study. This is the third reason this study needs to be done.

For the three reasons mentioned above, this study will apply *SPC* method to calculate the weights of the criteria of woodworking machinery. After that, ranking the alternatives will be done by using *CRADIS* method to choose the best alternatives for each kind of machinery. However, if ranking the alternatives is done using only one *CRADIS* method, it might cause mistakes because the method is not suiTable [13, 14]. For this reason, another *MCDM* method will also be used to ranking the alternatives in this study. The method that has just been mentioned is *CURLI* method [22]. The best alternatives ranked by *CRADIS* and *CURLI* methods will be compared to each other. The comparing result will lead to the most accurate conclusions. The reason why *CURLI* is used in this study is because this is one of the very few *MCDM* methods that do not need to calculate the weights of the criteria, which means, the ranking result does not depend on the weights of the criteria [23, 24]. This method was also confirmed to be equivalent to some other *MCDM* methods in some recent studies. In [24], the *CURLI* and *PEG* methods determined the same best alternative of the turning process. In [25], the *CURLI* method was confirmed to have equivalent efficiency with *PROMETHEE* and *CODAS* methods in ranking material types to make car protective cover; it is equivalent to *EDAS*, *TOPSIS* and *EXPROM2* methods when they are used to rank the material types to make gears; equivalent to *VIKOR* and *EXPROM2* when they are used to rank cutting toll material types. In [26], *CURLI* method was also confirmed to be equivalently effective with *R* and *CODAS* methods when used to select industrial robot; equivalent with 8 methods include *R*, *SAW*, *WASPAS*, *TOPSIS*, *VIKOR*, *MOORA*, *COPRAS* and *PIV* in selecting an option to lathe metal; and equivalent with *R* and *MABAC* methods in choosing an option to build a bridge. In [27], *CURLI* method was also confirmed to have equivalent efficiency with *R* method when used to rank car types.

The steps for implementation of *SPC*, *CRADIS* and *CURLI* methods are the main content presented in the second part of this study. The third part of this paper is the ranking results of wood milling machines, woof saw machines and wood planers done by different *MCDM* methods. The conclusions drawn from this study and what need to be done in the future are the ending content of this study.

2. Materials and methods

The steps to calculate the weights of the criteria according to *SPC* method [12]:

Step 1. Build a decision matrix (*DM*) includes m alternatives and n criteria as in the formula (1). Where x_{ij} is the value of criterion j of alternative i, with $j = 1 \div n$ and $i = 1 \div m$:

$$DM = \left[x_{ij}\right]_{m\times n} = \begin{matrix} A_1 \\ A_2 \\ \ldots \\ A_m \end{matrix}\begin{bmatrix} x_{11} & x_{12} & \ldots & x_{1n} \\ x_{21} & x_{22} & \ldots & x_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ x_{m1} & x_{m2} & \ldots & x_{mn} \end{bmatrix}. \quad (1)$$

Step 2. Calculate the *SPC* value for each criterion according to the formula (2):

$$SPC_j = \frac{\max(x_{ij}) + \min(x_{ij})}{2}. \quad (2)$$

Step 3. Create the absolute distance matrix according to the formula (3):

$$D = \left|d_{ij}\right|_{m\times n} = \begin{bmatrix} |x_{11} - SPC_1| & |x_{12} - SPC_2| & \ldots & |x_{1n} - SPC_n| \\ |x_{21} - SPC_1| & |x_{22} - SPC_2| & \ldots & |x_{2n} - SPC_n| \\ \ldots & \ldots & \ldots & \ldots \\ |x_{m1} - SPC_1| & |x_{m2} - SPC_2| & & |x_{mn} - SPC_n| \end{bmatrix}. \quad (3)$$

Step 4. Create the matrix of symmetric modules according to the formula (4):

$$R = \left|r_{ij}\right|_{m\times n} = \begin{bmatrix} \left|\frac{\sum_{i=1}^{m} d_{i1}}{m \times x_{11}}\right| & \left|\frac{\sum_{i=1}^{m} d_{i2}}{m \times x_{12}}\right| & \ldots & \left|\frac{\sum_{i=1}^{m} d_{in}}{m \times x_{1n}}\right| \\ \left|\frac{\sum_{i=1}^{m} d_{i1}}{m \times x_{21}}\right| & \left|\frac{\sum_{i=1}^{m} d_{i2}}{m \times x_{22}}\right| & \ldots & \left|\frac{\sum_{i=1}^{m} d_{in}}{m \times x_{2n}}\right| \\ \ldots & \ldots & \ldots & \ldots \\ \left|\frac{\sum_{i=1}^{m} d_{i1}}{m \times x_{m1}}\right| & \left|\frac{\sum_{i=1}^{m} d_{i2}}{m \times x_{mn}}\right| & \ldots & \left|\frac{\sum_{i=1}^{m} d_{in}}{m \times x_{mn}}\right| \end{bmatrix}. \quad (4)$$

Step 5. Calculate the symmetric modules of the criteria according to the formula (5):

$$Q = \left[q_{1j}\right]_{1\times n} = \begin{bmatrix} \frac{\sum_{i=1}^{m} r_{i1}}{m} & \frac{\sum_{i=1}^{m} r_{i2}}{m} & \ldots & \frac{\sum_{i=1}^{m} r_{in}}{m} \end{bmatrix}. \quad (5)$$

Step 6. Calculate the weights of the criteria according to the formula (6):

$$W=\left[w_{1j}\right]_{1\times n}=\left[\begin{matrix}\frac{q_1}{\sum_{j=1}^{n}q_j} & \frac{q_2}{\sum_{j=1}^{n}q_j} & \dots & \frac{q_n}{\sum_{j=1}^{n}q_j}\end{matrix}\right]. \quad (6)$$

The *CRADIS* method is used to rank the alternatives according to these following steps [15]:

Step 1. Build a decision matrix (the same as step 1 of *SPC* method).

Step 2. Normalizing the data according to the formulas (7) and (8):

$$n_{ij}=\frac{x_{ij}}{\max\left(x_{ij}\right)}. \quad (7)$$

$$n_{ij}=\frac{\min\left(x_{ij}\right)}{x_{ij}}. \quad (8)$$

Use (7) if j is the criterion as large as possible. Otherwise, use (8) if j is the criterion as small as possible.

Step 3. Calculate the weighted normalized values of the criteria according to the formula (9):

$$v_{ij}=n_{ij}\cdot w_j. \quad (9)$$

Where w_j is the weight of the criterion j.

Step 4. Determine the best alternative (t_i) and the worst alternative (t_{ai}) according to $t_i=max(v_{ij})$ and $t_{ai}=min(v_{ij})$.

Step 5. Calculate the deviation range compared with the absolute best alternative (d^+) and the deviation range compared with the absolute worst alternative (d^-) according to $d^+=t_i-v_{ij}$ and $d^-=v_{ij}-t_{ai}$.

Step 6. Calculate the functions S^+ and S^- according to the two corresponding formulas (10) and (11):

$$S^+=\sum_{j=1}^{n}d^+. \quad (10)$$

$$S^-=\sum_{j=1}^{n}d^-. \quad (11)$$

Step 7. Calculate the functions K_i^+ and K_i^- according to the two corresponding formulas (12) and (13):

$$K_i^+=\frac{S_0^+}{S_i^+}. \quad (12)$$

$$K_i^-=\frac{S_i^-}{S_0^-}. \quad (13)$$

Where $S_0^+=\min\left(S_i^+\right)$ and $S_0^-=\min\left(S_i^-\right)$, with $i=1\div m$.

Step 8. The M_i scores of the alternatives are calculated according to the formula (14). The alternative with the largest M_i value is the best one:

$$M_i=\frac{K_i^+ + K_i^-}{2}. \quad (14)$$

The steps to rank the alternatives according to the *CURLI* method are as follows [22]:

Step 1. Build a decision matrix (the same as step 1 of the SPC method).

Step 2. Build n square matrices of m levels, each square matrix is the scoring result for each criterion. The rule to score for each criterion is as follows. Assuming that criterion j which has its value at A_1 is better than its value at A_2, then score 1 in the cell corresponding to row 2 and column 1. Otherwise, let's score –1. Of course, if the values of criterion *j* at A_1 and A_2 are equal, then score 0 in the cell corresponding to row 2 and column 1. For the cells that belong to the main diagonal of the matrix, let's score 0. This matrix is called the scoring matrix for criterion *j*. The format of the scoring matrix for each criterion is shown in **Table 1**:

Table 1
Scoring matrix for criterion *j*

A/S	S_1	S_2	S_i	S_{m-1}	S_m
A_1	0	–1 (if A_2 is worse than A_1)	0 (if A_i is equal to A_1)	0 (if A_{m-1} is equal to A_1)	1 (if A_m is better than A_1)
A_2	1 (if A_1 is better than A_2)	0	1 (if A_i is better than A_2)	–1 (if A_{m-1} is worse than A_2)	0 (if A_m is equal to A_2)
A_i	1 (if A_1 is better than A_i)	1 (if A_2 is better than A_i)	0	–1 (if A_{m-1} is worse than A_i)	0 (if A_m is equal to A_i)
A_{m-1}	0 (if A_1 is equal to A_{m-1})	–1 (if A_2 is worse than A_{m-1})	0 (if A_{m-1} is equal to A_i)	0	–1 (if A_m is worse than A_{m-1})
A_m	–1 (if A_1 is worse than A_m)	1 (if A_2 is better than A_m)	–1 (if A_i is worse than A_m)	1 (if A_{m-1} is better than A_m)	0

Step 3. Adding all the scoring matrices for each criterion into a single matrix, let's obtain a matrix called the process scoring matrix.

Step 4. Rearrange the process scoring matrix by moving the rows and columns so the portion above the main diagonal has the highest proportion of cells with non-positive scores (negative or zero). Ideally, all points with non-positive values should lie above the main diagonal of the matrix, and all the cells with non-negative values lie under the main diagonal of the matrix. After rearranging the process scoring matrix, the alternative in row 1 is considered to be the best alternative.

3. Results and discussion

3. 1. Selecting wood milling machine

The information of wood milling machines are confirmed on the website of the supplier [28]. Four different wood milling machine types include E-3D-18*25-6H-LOCAL, E-3D-15*13-6H-LOCAL, E-3D-15*13-4H-LOCAL and E-3D-18*25-4H-LOCAL. They are denoted respectively by the alternatives A_1, A_2, A_3 and A_4.

Nine criteria used to describe for each alternative are also confirmed from the supplier, which are:

C_1: Working range in *X* axis (mm);

C_2: Working range in *Y* axis (mm);

C_3: Working range in *Z* axis (mm);

C_4: The spindle maximum speed (m/min);

C_5: The maximum movement speed (m/min);

C_6: The maximum working speed (m/min);

C_7: The maximum allowable humidity of wood (°C);

C_8: Flash memory (Mb);

C_9: Price (million dong). Million dong is a Vietnam currency unit, 1 million dong equals 42.65 dollars.

In these nine criteria, only C_9 is the smaller the better, all other sriteria are the larger the better. The values of the criteria for each machine types are summarized in **Table 2**.

What needs to be done now is ranking the alternatives in **Table 2** to choose out the best alternative. The best alternative is the one that ensures that the first eight criteria are considered the largest and the last criterion (C_9) is considered the smallest.

The first thing to be done is determining the weights of the criteria by using the *SPC* method.

The decision matrix is the data Table of the wood milling machines in **Table 2**.

Excel was used as the tool to perform all calculations in this study. The *SPC* values calculated according to the formula (2) are presented in **Table 3**.

Table 2

Wood milling machine data [28]

A/C	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
	max	**max**	**max**	**max**	**max**	**max**	**max**	**max**	**min**
A_1	1800	2500	180	24000	50	25	75	128	164
A_2	1500	1300	180	23000	42	22	70	100	149
A_3	1500	1000	150	20000	50	25	50	120	129
A_4	1800	2000	160	21500	50	25	50	120	154.56

Table 3

SPC values of the criteria

C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
1650	1750	165	22000	46	23.5	62.5	114	146.5

The absolute distance matrix is calculated according to the formula (3), the result is in **Table 4**:

Table 4

Absolute distance matrix

A/C	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	150	750	15	2000	4	1.5	12.5	14	17.5
A_2	150	450	15	1000	4	1.5	7.5	14	2.5
A_3	150	750	15	2000	4	1.5	12.5	6	17.5
A_4	150	250	5	500	4	1.5	12.5	6	8.06

The matrix of the symmetric modules is calculated according to the formula (4), the result is shown in **Table 5**:

Table 5

Matrix of the symmetric modules

A/C	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.0833	0.2200	0.0694	0.0573	0.0800	0.0600	0.1500	0.0781	0.0695
A_2	0.1000	0.4231	0.0694	0.0598	0.0952	0.0682	0.1607	0.1000	0.0764
A_3	0.1000	0.5500	0.0833	0.0688	0.0800	0.0600	0.2250	0.0833	0.0883
A_4	0.0833	0.2750	0.0781	0.0640	0.0800	0.0600	0.2250	0.0833	0.0737

The symmetric modules (Q) of the criteria are calculated according to the formula (5). The weights of the criteria (W) are calculated according to the formula (6). These values are summarized in **Table 6**:

Table 6

Symmetric modules and the weights of the criteria

–	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
Q	0.0917	0.3670	0.0751	0.0624	0.0838	0.0620	0.1902	0.0862	0.0770
W	0.0837	0.3350	0.0685	0.0570	0.0765	0.0566	0.1736	0.0787	0.0703

So, the weights of the criteria are determined. The next thing to do is using the *CRADIS* method to rank the wood milling machine.

Apply the two formulas (7) and (8), the normalized data is calculated in **Table 7**.

The weighted normalized data of the criteria is calculated according to the formula (10) and has the result shown in **Table 8**.

The values t_i and t_{ai} are shown in **Table 9**.

Table 7
Normalized data of the criteria

A/C	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7866
A_2	0.8333	0.5200	1.0000	0.9583	0.8400	0.8800	0.9333	0.7813	0.8658
A_3	0.8333	0.4000	0.8333	0.8333	1.0000	1.0000	0.6667	0.9375	1.0000
A_4	1.0000	0.8000	0.8889	0.8958	1.0000	1.0000	0.6667	0.9375	0.8346

Table 8
Weighted normalized data of the criteria

A/C	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.0837	0.3350	0.0685	0.0570	0.0765	0.0566	0.1736	0.0787	0.0553
A_2	0.0697	0.1742	0.0685	0.0546	0.0643	0.0498	0.1620	0.0615	0.0608
A_3	0.0697	0.1340	0.0571	0.0475	0.0765	0.0566	0.1157	0.0738	0.0703
A_4	0.0837	0.2680	0.0609	0.0511	0.0765	0.0566	0.1157	0.0738	0.0586

Table 9
Values t_i and t_{ai} of the criteria

–	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
t_i	0.0837	0.3350	0.0685	0.0570	0.0765	0.0566	0.1736	0.0787	0.0703
t_{ai}	0.0697	0.1340	0.0571	0.0475	0.0643	0.0498	0.1157	0.0615	0.0553

The functions d^+ are shown in **Table 10**:

Table 10
Functions d^+

A/C	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0150
A_2	0.0139	0.1608	0.0000	0.0024	0.0122	0.0068	0.0116	0.0172	0.0094
A_3	0.0139	0.2010	0.0114	0.0095	0.0000	0.0000	0.0579	0.0049	0.0000
A_4	0.0000	0.0670	0.0076	0.0059	0.0000	0.0000	0.0579	0.0049	0.0116

The functions d^- are shown in **Table 11**:

Table 11
Functions d^-

A/C	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.0139	0.2010	0.0114	0.0095	0.0122	0.0068	0.0579	0.0172	0.0000
A_2	0.0000	0.0402	0.0114	0.0071	0.0000	0.0000	0.0463	0.0000	0.0056
A_3	0.0000	0.0000	0.0000	0.0000	0.0122	0.0068	0.0000	0.0123	0.0150
A_4	0.0139	0.1340	0.0038	0.0036	0.0122	0.0068	0.0000	0.0123	0.0034

The two formulas (10) and (11) are used to calculate the functions S^+ and S^-. The functions K_i^+ and K_i^- are calculated according to the two corresponding formulas (12) and (13). The formula (14) are used to calculate the values M_i. All the values calculated are summarized in **Table 12**. The ranking result of the alternatives according to the values M_i is also in **Table 12**.

Thus, ranking the wood milling machines using the *CRADIS* method has been done. Accordingly, the priority order of the machines is as follows $A_1 > A_4 > A_2 > A_3$. Now, ranking these machines using the *CURLI* method will be done to make a standard for comparison between two methods (*CRADIS* and *CURLI*).

The results of scoring for the nine criteria are presented in nine tables, from **Tables 13–21**:

Table 12

Some functions in CRADIS and ranking the alternatives

A/C	S^+	S^-	K_i^+	K_i^-	M_i	Rank
A_1	0.0150	0.3300	1	1	1	1
A_2	0.2344	0.1106	0.0640	0.3352	0.1996	3
A_3	0.2987	0.0463	0.0502	0.1404	0.0953	4
A_4	0.1550	0.1900	0.0968	0.5759	0.3363	2

Table 13

Scoring matrix for C_1

A/S	S_1	S_2	S_3	S_4
A_1	0	–1	–1	0
A_2	1	0	0	1
A_3	1	0	0	1
A_4	0	–1	–1	0

Table 14

Scoring matrix for C_2

A/S	S_1	S_2	S_3	S_4
A_1	0	–1	–1	–1
A_2	1	0	–1	1
A_3	1	1	0	1
A_4	1	–1	–1	0

Table 15

Scoring matrix for C_3

A/S	S_1	S_2	S_3	S_4
A_1	0	0	–1	–1
A_2	0	0	–1	–1
A_3	1	1	0	1
A_4	1	1	–1	0

Table 16

Scoring matrix for C_4

A/S	S_1	S_2	S_3	S_4
A_1	0	1	1	1
A_2	–1	0	1	1
A_3	–1	–1	0	–1
A_4	–1	–1	1	0

Table 17

Scoring matrix for C_5

A/S	S_1	S_2	S_3	S_4
A_1	0	–1	0	0
A_2	1	0	1	1
A_3	0	–1	0	0
A_4	0	–1	0	0

Table 18

Scoring matrix for C_6

A/S	S_1	S_2	S_3	S_4
A_1	0	–1	0	0
A_2	1	0	1	1
A_3	0	–1	0	0
A_4	0	–1	0	0

Table 19

Scoring matrix for C_7

A/S	S_1	S_2	S_3	S_4
A_1	0	–1	–1	–1
A_2	1	0	–1	–1
A_3	1	1	0	0
A_4	1	1	0	0

Table 20

Scoring matrix for C_8

A/S	S_1	S_2	S_3	S_4
A_1	0	–1	–1	–1
A_2	1	0	1	1
A_3	1	–1	0	0
A_4	1	–1	0	0

Table 21

Scoring matrix for C_9

A/S	S_1	S_2	S_3	S_4
A_1	0	1	1	1
A_2	–1	0	1	–1
A_3	–1	–1	0	–1
A_4	–1	1	1	0

Adding the scoring matrices for each criterion together (from **Table 13** to **Table 21**) let's obtain the process scoring matrix as in **Table 22**.

After moving the rows and columns in **Table 22**, let's obtain the result as in **Table 23**.

So, all the cells lie above the main diagonal of the matrix in **Table 23** have negative values. On the contrary, all the cells lie under the main diagonal have positive values. Accordingly, the priority order of the alternatives (milling machine types) is $A_1 > A_4 > A_3 > A_2$.

Fig. 1 is the chart of comparison between the wood milling machine types using the *CRADIS* and *CURLI* methods.

Table 22
Process scoring matrix

A/*S*	S_1	S_2	S_3	S_4
A_1	0	–4	–3	–2
A_2	4	0	2	3
A_3	3	–2	0	1
A_4	2	–3	–1	0

Table 23
Process scoring matrix after moving rows and columns

A/*S*	S_1	S_2	S_3	S_4
A_1	0	–2	–3	–4
A_2	2	0	–1	–3
A_3	3	1	0	–2
A_4	4	3	2	0

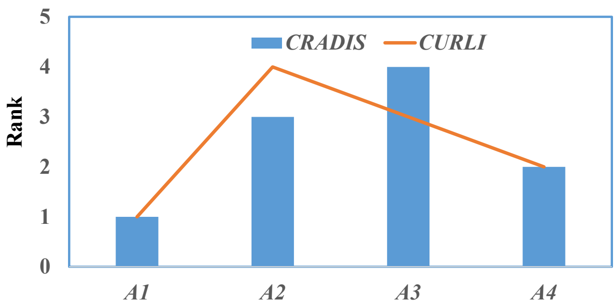

Fig. 1. Ranking the milling machines using different methods

Observing **Fig. 1**, both used methods determined A_1 as ranked 1st alternative (the best alternative). Which means, finding the best alternative in this case is equivalent for the two methods *CRADIS* and *CURLI*. In addition, alternative A_4 is also determined as rank 2nd when using both methods. So, among four types of wood milling machine including E-3D-18*25-6H-LOCAL, E-3D-15*13-6H-LOCAL, E-3D-15*13-4H-LOCAL and E-3D-18*25-4H-LOCAL, E-3D-18*25-6H-LOCAL is considered the best, and E-3D-18*25-4H-LOCAL is determined as ranked 2nd alternative.

3. 2. Selecting wood saw machine

Five types of wood saw machine, which have been chosen to be ranked in this study, were chosen from the supplier's website [29]. The machine types are denoted as the corresponding alternatives as follows:

A_1: SKU-GKS 190;
A_2: SKU-HS7010;
A_3: SKU-HS7600;
A_4: SKU-GKS 235;
A_5: SKU-CS18528.

Six criteria were used to describe for each alternative include:

C_1: No-load speed (rev/min);
C_2: Maximum depth of cut when the tool path makes an angle of 90° with the surface to be cut (mm);
C_3: Maximum depth of cut when the tool path makes an angle of 45° with the surface to be cut (mm);
C_4: Saw blade diameter (mm);

C_5: Weight (kg);

C_6: Price (million dong).

In six mentioned criteria, the first four criteria are the larger the better, the other two are the smaller the better.

The information of five wood saw machine types have been summarized in **Table 24**:

Table 24

Information of wood saw machine types [29]

A/C	C_1	C_2	C_3	C_4	C_5	C_6
	max	max	max	max	min	min
A_1	5200	67	48	184	3.6	2.166
A_2	5500	67	45	190	4	2.256
A_3	5200	64	42	185	3.8	2.344
A_4	5300	85	65	235	7.6	3.353
A_5	4800	65	44	185	3.5	1.179

The *SPC* method has been used again to calculate the weights of the criteria (from C_1 to C_6), which have the corresponding values are 0.0312, 0.1127, 0.1664, 0.1050, 0.3852 and 0.1996.

The work of ranking the wood saw machine types using *CRADIS* and *CURLI* methods are the same as example 1. The chart of comparison of wood saw machine types have been presented in **Fig. 2**:

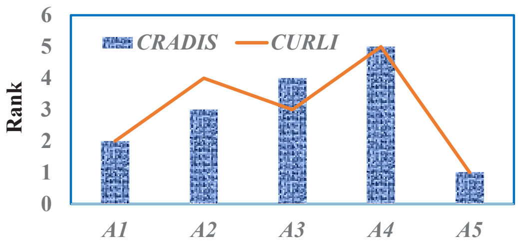

Fig. 2. Ranking wood saw machine types using different methods

Observing **Fig. 2**, it is possible to see that although the ranking results are not the same when using two methods *CRADIS* and *CURLI*. However, both methods have shown that A_5 is the best alternative, A_1 is the second-ranked alternative, and A_4 is the worst alternative. Which means, determining the best alternative in this case is equivalent when using two methods CRADIS and CURLI. Accordingly, among five types of wood saw machine including SKU-GKS 190, SKU-HS7010, SKU-HS7600, SKU-GKS 235 and SKU-CS18528, the best alternative is SKU-CS18528, in contrast, SKU-GKS 235 is the worst alternative.

3. 3. Selecting wood planer

The information from the supplier is used again to determine the data of wood planer in this case [30]. Six different types of wood planer chosen from the supplier include A_1 (Makita M1901B), A_2 (Bosch GHO 6500), A_3 (Stanley STEL 630), A_4 (Dewalt D26676), A_5 (Crown CT14019) and A_6 (MAKITA M1100B).

Six criteria were used to describe each machine types are also produced by the supplier, which are:

C_1: Width of planning line (mm);

C_2: Maximum depth of planning line (mm);

C_3: Maximum no-load speed (v/min);

C_4: Total length of the machine (mm);

C_5: Weight (kg);

C_6: Price (million dong).

Among the six mentioned criteria, C_1, C_2 and C_3 are the larger the better. The other three are the smaller the better. The values of their criteria of each alternative are summarized in **Table 25**:

Table 25
Data of wood planer [30]

A/*C*	C_1	C_2	C_3	C_4	C_5	C_6
A_1	82	2	16000	285	3	1.586
A_2	82	2.6	16500	300	2.8	1.529
A_3	82	1.8	16000	290	2.5	1.390
A_4	102	1	17000	280	2.7	2.430
A_5	82	2	11500	280	2.7	1.135
A_6	82	3	18000	390	4.6	2.218

Once again, the *SPC* method has been used to calculate the weights of the criteria (from C_1 to C_6), with values of 0.0956, 0.2063, 0.1132, 0.1328, 0.2351, and 0.2170.

The application of the two methods *CRADIS* and *CURLI* to rank the wood planer types in this case is done in the same way as in example 1. The ranking results are presented in **Fig. 3**:

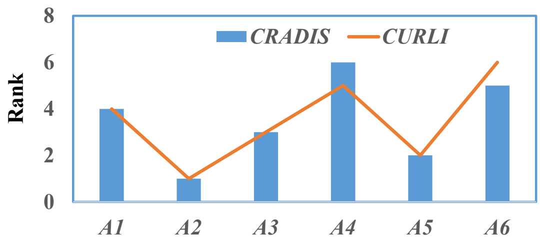

Fig. 3. Ranking the wood planer types using different methods

Observing **Fig. 3**, it is possible to see that the alternatives which are first-ranked (A_2), second-ranked (A_5), third-ranked (A_3) and fourth-ranked (A_1) are all the same when using *CRADIS* method and *CURLI* method. Accordingly, the efficiency of both methods is equivalent in this case. So, among six types of wood planer that were surveyed, Bosch GHO 6500 is the best type, the second-ranked is Crown CT14019, the third-ranked is Stanley STEL 630 and Dewalt D26676 is fourth-ranked.

By ranking the three kinds of wood working machinery above, it is possible to see that although the number of criteria and alternatives in each case is different. In detail, in the first case, there are four alternatives and nine criteria. In the second case, there are five alternatives and six criteria. In the third case, there are six alternatives and six criteria. The number of criteria of each kinds case is also different in each case. Specifically, in the first case, there are eight criteria, which are the larger the better, and one criterion, which is the smaller, the better. In the second case, there are four criteria, which are the larger the better, and two criteria, which are the smaller, the better. In the third case, the number of the criteria, which are the larger the better, and the number of the criteria which are the smaller the better are equal (both equals 3). Although there are many differences in each case, the best alternative determined in each case is still the same when using two different methods *CRADIS* and *CURLI*. This gave a conclusion that the two methods are suitable for multi-criteria decision-making in the selection of these three machinery kinds. The two methods *CRADIS* and *CURLI* have also showed that they are equally effective in finding out the best alternative, at least, in the case of ranking woodworking machinery.

3. 4. Limitations of the study and development prospects

In this study, when using the *CRADIS* method, let's only consider the case when the weights of the criteria are calculated using the *SPC* method. When using other weighting methods, whether or not the ranking of the alternatives will change will be a question that needs to be answered in the next study. In addition, the *SPC* method cannot be used to weight the criteria if the criteria are qualitative. This is also work that needs to be upgraded in the future.

Ranking and selecting woodworking machinery kinds are the best when considering more criteria such as energy consumption, environmental damage, warranty, etc. is a must-do in the future.

4. Conclusions

This is the first time the *SPC* method has been used to calculate the weights of the criteria of woodworking machinery. This is also the first time the *CRADIS* method and the *CURLI* method have been used to rank these machinery kinds.

The two methods *CRADIS* and *CURLI* are confirmed to be suiTable and equivalently effective in finding out the best woodworking machinery kinds.

Among the considered kinds of machinery in this study, E-3D-18*25-6H-LOCAL is the best milling machine type, the best saw machine type is SKU-CS18528, and Bosch GHO 6500 is the best planer.

The *SPC*, *CRADIS* and *CURLI* methods also provide a certain degree of reliability in selecting other machinery kinds (chisels, grinders, etc.), first of all, in the selection of woodworking equipment.

When considering the weight of the criteria, a combination of the CRADIS method and the SPC method recommended is used. Meanwhile, the CURLI method is recommended to be used when making the selection of the best alternative regardless of the weight of the criteria.

Conflict of interest

The authors declare that there is no conflict of interest in relation to this paper, as well as the published research results, including the financial aspects of conducting the research, obtaining and using its results, as well as any non-financial personal relationships.

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Data availability

Manuscript has data included as electronic supplementary material.

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