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SELECTION OF WELDING ROBOT BY MULTI-CRITERIA DECISION-MAKING METHOD

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Welding is a method to join parts together by a stable connection. Welding is used in many different fields. The limitations of manual welding methods are gradually eliminated when using welding robots. The selection of a welding robot has a great influence on the efficiency of the welding process. Choosers (customers) often encounter problems when choosing among many products that are available in the market. During this study, seven types of robots were given to make a choice including AR700, AR900, AR1440, AR1730, AR2010, MA3120, VA1400 II. These seven options are commonly used in welding processes. There are a variety of different parameters (criteria) used to evaluate each of these robots. However, the value of the criteria in the robots is very different. The selection of a robot that is considered the best should be based on all those criteria. At this point, the selection of robots is called MCDM (Multi-Criteria Decision-Making). In this research, two MCDM methods were used to rank the types of robots: MARCOS (Measurement of Alternatives and Ranking according to COmpromise Solution) and PSI (Preference Selection Index). The determination of important quantities for the criteria has been carried out by various methods, including the MEREC (MEthod based on the Removal Effects of Criteria), EQUAL, ROC (Rank Order Centroid) and RS (Rank Sum) methods. The MARCOS method was used four times corresponding to four different sets of weights. Meanwhile, when using the PSI method, we do not need to calculate the weights for the criteria. All five ranking results indicate the same best alternative. The results indicate that MA3120 is the best one. The two methods MARCOS and PSI are reliable enough to be used when multi-criteria decision-making is required, firstly, in the selection of welding robots.

Keywords: welding robot selection, multi-criteria decision-making, MCDM, MARCOS, PSI

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1. Introduction

Welding technology has been rapidly developed in recent times. It is one of the main technologies of heavy industries. Welding methods are applied in many fields such as shipbuilding, automobiles, motorcycles, oil and gas, construction, etc. Despite its high multimeterity, the manual welding method (using the operation of the worker) has been known to have many limitations, such as: affecting the health of workers, the quality of the structure is difficult to ensure stability, the level of waste of self-welding, etc. In particular, manual welding is difficult to apply to large structures, for example in the shipbuilding industry. Welding robots were born and contributed to significantly reducing the above-mentioned limitations. To choose a suitable welding robot, customers must consider many criteria of each type of product. Some criteria are commonly used to describe each type of welding robot such as: cost, weld accuracy, number of degrees of freedom of the robot arm, range of the robot arm, ability to control the welding power supply, type of welding gun, welding wire supply mechanism, welding positioning and fixing mechanism, etc. The value of these parameters for each type of welding robot is very different, even contradictory. For example, if a product has a low cost, the accuracy is also low, and vice versa. Choosing a robot based on only one or several criteria can lead to mistakes. Therefore, the selection of welding robots by multi-criteria decision-making techniques is a topic of interest.

2. Literature review and problem statement

The MCDM problem has been applied to robot selection. In [1], the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method was used to rank robots. Eight types of robots were selected for the survey. Each type of robot is evaluated using five different criteria. This research has selected a type of robot that simultaneously ensures the maximum four criteria (including mechanical weight, repeatability, payload, maximum reach) and the smallest average power consumption. In [2], the CODAS (COmbinative Distance-based Assessment) method was used to rank seven different types of robots. Five criteria were used to describe each type of robot including load capacity, maximum tip speed, repeatability, memory capacity, and manipulator reach. Six different data normalization methods were used in conjunction with the CODAS method. Five of the six data normalization methods when combined with the CODAS method found the best solution. This study has found an option that simultaneously guarantees the minimum repeatability and the largest remaining four criteria. In [3], the ranking of robots was performed using the EDAS (Evaluation Based on Distance from Average Solution) method. Five types of robots were selected to perform the ranking. Four criteria were used to describe each alternative. The best solution was found to be the one that simultaneously guaranteed the minimum repeatability error and the maximum three other criteria (including load capacity, vertical reach, and degrees of freedom). In [4], two methods EDAS and VIKOR (VIse Kriterijumska Optimizacija i kompromisno Resenje) were used simultaneously to rank five different types of robots. Both methods, when used, consistently determine the best alternative. In [5], two different MCDM methods were also used to rank the robot types, R (Ranking of attributes and alternatives) and CURLI (Collaborative Unbiased Rank List Integration). Both of these methods, when used, find the best robot. The best option is the one that simultaneously guarantees the smallest repeatability and the largest four other criteria (including load capacity, maximum tip speed, memory capacity, and manipulator reach). In [6], two methods WARA (Weighted Average Return on Assets) and COCOSO (COmbined COmpromise SOlution) were used to rank twelve different robots. Both of these methods together determine the best solution. In [7], three methods TOPSIS, ARAS (Additive Ratio Assessment), COPRAS (COmplex PRroportional Assessment) were used simultaneously to rank twelve types of robots. The best solution found using the above three methods is the same. In [8], ten different MCDM methods were used to rank seven types of robots. Ten methods were used including SAW (Simple Additive Weighting), WPM (Weighted Product Method), AHP (Analytic Hierarchy Process), TOPSIS, GTMA (Graph Theory and Matrix Approach), VIKOR, ELECTRE (ELimination and Et Choice Translating Reality), PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluation), GRA (Grey Relational Analysis), and ROVM (Range of Value Method). It was found that the best solution was found regardless of the MCDM method used. However, the robots mentioned in the above study are not welding robots. Welding robots have never been considered in a multi-criteria decision problem. The classification of welding robots was performed for the first time in this study. This is the first reason for this study to be done.

Some of the studies just listed above show that MCDM methods have been used quite a lot for multi-criteria decision-making in choosing robots. MARCOS and PSI are two of the MCDM methods that have been used quite commonly for multi-criteria decision-making in many different cases. MARCOS is a method found recently (2020) [9]. This method has shown many confirmed advantages such as: high stability when ranking options, it is possible to determine the best option regardless of the number of options as well as not depending on the weighting method used [10]. PSI is a method that has different characteristics from many other MCDM methods. The difference is that when using the PSI method we do not need to determine the weights of criteria [11]. This is also a distinguishing feature between the PSI method and the MARCOS method. Despite this, MARCOS and PSI have been used for multi-criteria decision-making in a variety of problems. But by all our efforts over a long period of time, we have yet to find any documentation that has applied these two methods used in multi-criteria decision-making for robot selection. This gap motivated us to do this research. This is the second reason for doing this study.

As mentioned above, when using the MARCOS method to rank options, it is necessary to determine the weights of the criteria. However, the results of the ranking of options are highly dependent on the weighting method used [12, 13]. An option may be considered the best for one set of weights, but it may also be the least option, even the worst for another set of weights [12, 13]. Therefore, in order to have a solid basis for asserting that a certain option is the best, it is necessary to rank those options with multiple sets of weights determined by different methods.

MEREC is a method of determining weights for recently found criteria (2021) [14]. It is considered a highly accurate method and is recommended for use [15]. Therefore, MEREC was also chosen in this study to determine the weights of the robot's criteria. In addition to MEREC, three other weighting methods were also used in this study, namely EQUAL, ROC and RS methods. The reason these three methods have also been used is their simplicity. Determining the weights of criteria for each of these methods requires only one simple formula [12, 13]. However, these four methods have also never been used to weigh the welding robot criteria. This reason was the third motivation that prompted us to carry out this study.

The use of two MCDM methods with different characteristics (MARCOS and PSI) along with four different weighting methods was expected to yield a conclusion with the highest reliability.

3. The aim and objectives of the study

The aim of this study is to develop the principle of choosing the best welding robot.

To achieve this aim, the following objectives are accomplished:

– to assess and calculate the weights of criteria by using the MEREC, EQUAL, ROC and RS methods;

– to solve the MCDM problem to find the best welding robot using the MARCOS and PSI methods.

4. Materials and methods

4. 1. Methods for determining weights

The MEREC method is used to calculate the weight in the following steps [14]:

Step 1. Develop a decision-making matrix consisting of m options and n criteria. Where y_{ij} is the value of criterion j for option i, where j=1÷n and i=1÷m. Criteria of the form as large as possible are called criteria of type B. Criteria of as small as possible form are called criteria of type C.

Step 2. Calculate the standardized values n_{ij} by equations (1) and (2):

$$n_{ij} = \frac{\min y_{ij}}{y_{ij}} \text{ if } j \in B. \quad (1)$$

$$n_{ij} = \frac{y_{ij}}{\max y_{ij}} \text{ if } j \in C. \quad (2)$$

Step 3. Calculate the overall performance of the options S_i by equation (3):

$$S_i = Ln\left[1 + \left(\frac{1}{n}\sum_{j}^{n}\left|Ln\left(n_{ij}\right)\right|\right)\right]. \quad (3)$$

Step 4. Calculate the performance of the alternative options S'_{ij} by equation (4):

$$S'_{ij} = Ln\left[1 + \left(\frac{1}{n}\sum_{k,k\neq j}^{n}\left|\mathrm{Ln}\left(n_{ij}\right)\right|\right)\right]. \quad (4)$$

Step 5. Calculate the absolute value of the deviations E_j by equation (5):

$$E_j = \sum_i^m \left| S'_{ij} - S_i \right|. \quad (5)$$

Step 6. Calculate the weights for the criteria w_j by equation (6):

$$w_j = \frac{E_j}{\sum_k^n E_k}. \quad (6)$$

The EQUAL method is used to calculate the weights of the criteria w_j by equation (7) [12, 13]:

$$w_j = \frac{1}{n}. \quad (7)$$

The ROC weighting method is used to calculate the weights of the criteria w_j by equation (8) [12, 13]:

$$w_j = \frac{1}{n}\sum_{k=i}^{n}\frac{1}{k}. \quad (8)$$

The RS weighting method is used to calculate the weights of the criteria w_j by equation (9) [12, 13]:

$$w_j = \frac{2(n+1-i)}{n(n+1)}. \quad (9)$$

The above equations are used to calculate the weights of the welding robot criteria in the next part of this paper.

4. 2. Multi-Criteria Decision-Making method

4. 2. 1. Measurement of Alternatives and Ranking according to Compromise Solution method

The MARCOS method is used to rank options in the following sequence [9].

Step 1. Similar to step 1 of the MEREC method.

Step 2. Building an initial matrix expansion by adding an ideal solution *AI* and a solution against the ideal solution *AAI*:

$$Y = \begin{matrix} AAI \\ A1 \\ \vdots \\ AI \end{matrix} \begin{bmatrix} y_{aa1} & y_{aa2} & \cdots & y_{aan} \\ y_{11} & y_{12} & \cdots & y_{1n} \\ \vdots & \vdots & \vdots & \vdots \\ y_{ai1} & y_{ai2} & \cdots & y_{ain} \end{bmatrix}, \quad (10)$$

where:

– if $j \in B$:

$AAI = \min(y_{ij})$; $i=1, 2, ..., m$; $j=1, 2, ..., n$.

$AI = \max(y_{ij})$; $i=1, 2, ..., m$; $j=1, 2, ..., n$.

– if $j \in C$:

$AAI = \max(y_{ij})$; $i=1, 2, ..., m$; $j=1, 2, ..., n$.

$AI = \min(y_{ij})$; $i=1, 2, ..., m$; $j=1, 2, ..., n$.

Step 3. Calculate the normalized values u_{ij} following (11) and (12):

$$u_{ij} = \frac{y_{AI}}{y_{ij}} \text{ if } j \in C, \quad (11)$$

$$n_{ij} = \frac{y_{ij}}{y_{AI}} \text{ if } j \in B. \quad (12)$$

Step 4. Calculate the standardized values considering the weight c_{ij} by equation (13):

$$c_{ij} = u_{ij} \cdot w_j, \quad (13)$$

where w_j is the weight of criteria *j*.

Step 5. Calculate the coefficients K_i^+ and K_i^- following (14) and (15):

$$K_i^- = \frac{S_i}{S_{AAI}}, \quad (14)$$

$$K_i^+ = \frac{S_i}{S_{AI}}, \quad (15)$$

where S_i, S_{AAI} and S_{AI} are respectively the sums of the values of c_{ij}, y_{aai} and y_{ai}, where $i=1, 2, ..., m$.

Step 6. Calculate $f(K_i^+)$ and $f(K_i^-)$ following (16) and (17):

$$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-}. \quad (16)$$

$$f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-}. \quad (17)$$

Step 7. Calculate $f(K_i)$ by equation (18):

$$f(K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1 - f(K_i^+)}{f(K_i^+)} + \frac{1 - f(K_i^-)}{f(K_i^-)}}. \quad (18)$$

Step 8. Rank the options in decreasing order of the $f(K_i)$ values.

4. 2. 2. Preference Selection Index method

The order of ranking options according to the PSI method is as follows [11].

Step 1. Similar to step 1 of the MEREC method.

Step 2. Standardize the data n_{ij} following (19) and (20):

$$n_{ij} = \frac{y_{ij}}{\max y_{ij}} \text{ if } j \in B, \quad (19)$$

$$n_{ij} = \frac{\min y_{ij}}{y_{ij}} \text{ if } j \in C. \quad (20)$$

Step 3. Calculate the average value of standardized data n following (21):

$$n = \frac{1}{n}\sum_{i=1}^{n} n_{ij}. \quad (21)$$

Step 4. Calculate the priority value from the average value φ_j following (22):

$$\varphi_j = \sum_{i=1}^{n} \left(n_{ij} - n\right)^2. \quad (22)$$

Step 5. Calculate the deviation in the priority value ϕ_j by equation (23):

$$\phi_j = 1 - \varphi_j. \quad (23)$$

Step 6. Calculate the overall priority value for the targets β_j by equation (24):

$$\beta_j = \frac{\phi_j}{\sum_{j=1}^{n} \phi_j}. \quad (24)$$

Step 7. Calculate the value θ_i of each plan by equation (25):

$$\theta_i = \sum_{j=1}^{n} n_{ij} \cdot \beta_j. \quad (25)$$

Step 8. Rank the options in decreasing order of the θ_i value.

5. Results of the selection of welding robots

5. 1. Weighting for welding robot criteria

Seven types of welding robots that are currently the most popular on the Vietnamese market have been selected for consideration. The six criteria for evaluating the types of robots provided by the supplier include: horizontal reach, vertical reach, price, error, load capacity, and number of poles. The value of the criteria in each product is summarized in Table 1 [16].

Table 1

Parameters of some types of welding robots [16]

Type	C1	C2	C3	C4	C5	C6
AR700	727	1312	6809	4 %	8	6
AR900	927	1693	6170	6 %	7	6
AR1440	1440	2511	4213	12 %	12	6
AR1730	1730	3089	5532	12 %	25	6
AR2010	2010	3649	6000	16 %	12	6
MA3120	3121	5616	5319	16 %	6	6
VA1400 II	1434	2475	3553	16 %	3	7

In Table 1:
– C1 – Horizontal reach (mm);
– C2 – Vertical reach (mm);
– C3 – Price (USD);
– C4 – Error (% mm);
– C5 – Load capacity (kg);
– C6 – Number of poles.

In which C3 and C4 are two criteria of type *C*. In contrast, the other four criteria are criteria of type *B*.

Using formulas from (1) to (6), the weights of the criteria were calculated according to the MEREC method. Weighting for criteria according to the EQUAL, ROC and RS methods corresponds to the use of equations (7), (8) and (9). The weights of the criteria that were calculated according to different methods are summarized in Table 2.

The data in Table 2 show that the weights of the criteria are different when calculated by different methods. For the two methods ROC and RS, the weights of the criteria decrease in order of the criteria.

Table 2

Weights of criteria

Weighting method	C1	C2	C3	C4	C5	C6
MEREC	0.2594	0.2554	0.0931	0.1775	0.2067	0.0079
EQUAL	1/6	1/6	1/6	1/6	1/6	1/6
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

5. 2. Rating of welding robots

Eight steps of the MARCOS method were used to rank the robots:

– build a decision-making matrix. This matrix is a table of data containing information about the seven types of robots (Table 1);

– the extended initial matrix is constructed by equation (10), whose value is as in Table 3.

Table 3

Extended initial matrix

Type	C1	C2	C3	C4	C5	C6
AAI	727	1312	6809	16%	3	6
AR700	727	1312	6809	4%	8	6
AR900	927	1693	6170	6%	7	6
AR1440	1440	2511	4213	12%	12	6
AR1730	1730	3089	5532	12%	25	6
AR2010	2010	3649	6000	16%	12	6
MA3120	3121	5616	5319	16%	6	6
VA1400 II	1434	2475	3553	16%	3	7
AI	3121	5616	3553	4%	25	7

Two equations (11) and (12) were used to calculate the normalized values for the criteria, the results of which are summarized in Table 4.

Table 4

Standardized values of criteria in MARCOS

Type	C1	C2	C3	C4	C5	C6
AAI	0.2329	0.2336	0.5218	0.2500	0.1200	0.8571
AR700	0.2329	0.2336	0.5218	1.0000	0.3200	0.8571
AR900	0.2970	0.3015	0.5759	0.6667	0.2800	0.8571
AR1440	0.4614	0.4471	0.8433	0.3333	0.4800	0.8571
AR1730	0.5543	0.5500	0.6423	0.3333	1.0000	0.8571
AR2010	0.6440	0.6498	0.5922	0.2500	0.4800	0.8571
MA3120	1.0000	1.0000	0.6680	0.2500	0.2400	0.8571
VA1400 II	0.4595	0.4407	1.0000	0.2500	0.1200	1.0000
AI	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

The standardized values consider the weights of the criteria calculated by equation (13). First of all, the weights are calculated by the MEREC method (in Table 2). Calculation results are synthesized in Table 5.

Equations (14) to (18) are used respectively to calculate the values K_i^-, K_i^+, $f\left(K_i^-\right)$, $f\left(K_i^+\right)$ and $f\left(K_i\right)$. All of these values are summarized in Table 6. The results of ranking robots according to the value of $f\left(K_i\right)$ are also summarized in Table 6.

Table 5

Standardized values of criteria weights

Type	C1	C2	C3	C4	C5	C6
AAI	0.0604	0.0597	0.0486	0.0444	0.0248	0.0067
AR700	0.0604	0.0597	0.0486	0.1775	0.0661	0.0067
AR900	0.0771	0.0770	0.0536	0.1183	0.0579	0.0067
AR1440	0.1197	0.1142	0.0786	0.0592	0.0992	0.0067
AR1730	0.1438	0.1405	0.0598	0.0592	0.2067	0.0067
AR2010	0.1671	0.1660	0.0552	0.0444	0.0992	0.0067
MA3120	0.2594	0.2554	0.0622	0.0444	0.0496	0.0067
VA1400 II	0.1192	0.1126	0.0931	0.0444	0.0248	0.0079
AI	0.2594	0.2554	0.0931	0.1775	0.2067	0.0079

Table 6

Parameters in MARCOS and ranking of robots

Type	K_i^-	K_i^+	$f(K_i^-)$	$f(K_i^+)$	$f(K_i)$	Rank
AR700	3.3997×10^{-5}	4.7227×10^{-5}	0.581443	0.418557	2.6125×10^{-5}	5
AR900	3.1690×10^{-5}	4.4022×10^{-5}			2.4352×10^{-5}	7
AR1440	3.8743×10^{-5}	5.3820×10^{-5}			2.9772×10^{-5}	4
AR1730	5.0030×10^{-5}	6.9500×10^{-5}			3.8446×10^{-5}	2
AR2010	4.3688×10^{-5}	6.0690×10^{-5}			3.3573×10^{-5}	3
MA3120	5.4989×10^{-5}	7.6388×10^{-5}			4.2256×10^{-5}	1
VA1400 II	3.2609×10^{-5}	4.5300×10^{-5}			2.5059×10^{-5}	6

Thus, the ranking of options using the MARCOS method ended with the weights of the criteria calculated according to the MEREC method. For the remaining three weighted sets, the ranking of options using the MARCOS method is done in the same way. Table 7 is the ranking of robots using different weighting methods.

According to the data in Table 7, the results of the classification of options are not the same with different weighting methods. This is also consistent with the statement already mentioned in many documents [17]. However, for all four weighting methods, MA3120 is considered the best option. This reaffirmed the advantages of the previously stated MARCOS method [10]. In short, we have enough solid grounds to claim that MA3120 is the best of the seven robots considered in this study.

Eight steps of the PSI method were used to rank the robots.

– the decision matrix is a table of figures on the types of robots (Table 1);

– two equations (19) and (20) were used to calculate the normalized values. The results are summarized in Table 8.

Table 7

Ranking of options using the MARCOS method with different weighting methods

Type	Weighting method			
	MEREC	EQUAL	ROC	RS
AR700	5	6	7	6
AR900	7	7	6	7
AR1440	4	4	4	4
AR1730	2	2	3	2
AR2010	3	3	2	3
MA3120	1	1	1	1
VA1400 II	6	5	5	5

Table 8

Standardized values of criteria by the PSI method

Type	C1	C2	C3	C4	C5	C6
AR700	0.2329	0.2336	0.5218	1.0000	0.3200	0.8571
AR900	0.2970	0.3015	0.5759	0.6667	0.2800	0.8571
AR1440	0.4614	0.4471	0.8433	0.3333	0.4800	0.8571
AR1730	0.5543	0.5500	0.6423	0.3333	1.0000	0.8571
AR2010	0.6440	0.6498	0.5922	0.2500	0.4800	0.8571
MA3120	1.0000	1.0000	0.6680	0.2500	0.2400	0.8571
VA1400 II	0.4595	0.4407	1.0000	0.2500	0.1200	1.0000

The average standardized value is calculated by equation (21). The priority value from the average value is calculated by equation (22). Using equation (23), the deviation in the priority value is calculated. The overall priority value for criteria is formulated (24). All of these values are synthesized in Table 9.

The value θ_i of each plan was calculated by equation (25). The calculated values are synthesized in Table 10. Ranking results are also synthesized in Table 10.

Thus, the ranking of robots by the PSI method has also been completed. The ranking results of welding robots by different methods are summarized in Table 11.

Table 9

Parameters in the PSI method

Parameter	C1	C2	C3	C4	C5	C6
n	0.5213	0.5175	0.6919	0.4405	0.4171	0.8776
ϕ_j	0.3862	0.3895	0.4960	0.1732	0.4955	0.0175
$\varnothing j$	0.6138	0.6105	0.8268	0.5040	0.5045	0.9825
β_j	0.1519	0.1510	0.2045	0.1247	0.1248	0.3056

Table 10

Value θ_i of options and ranking of options

Type	θ_i	Rank
AR700	0.6039	6
AR900	0.5884	7
AR1440	0.6735	4
AR1730	0.7269	2
AR2010	0.6701	5
MA3120	0.7626	1
VA1400 II	0.6926	3

Table 11

Results of ranking welding robots by different methods

Type	MARCOS				PSI
	MEREC	EQUAL	ROC	RS	
AR700	5	6	7	6	6
AR900	7	7	6	7	7
AR1440	4	4	4	4	4
AR1730	2	2	3	2	2
AR2010	3	3	2	3	5
MA3120	1	1	1	1	1
VA1400 II	6	5	5	5	3

The discussion of the ranking results of welding robots is presented in the following section.

6. Discussion of multi-criteria decision-making results

Analysis of the data in Table 11 shows that:

– the use of MARCOS and PSI methods along with the weight calculation by MEREC, EQUAL, ROC and RS to solve the MCDM problem for welding robot rating will give different ranking results. This is also consistent with the statement in the published document [17];

– all two MCDM methods mentioned above have identified the same best solution, option MA3120. That result does not depend on the weighting of the indicators according to the MEREC, EQUAL, ROC and RS methods. That allows us to say that determining the best alternative does not depend on the MCDM method and the weighting method used (at least with the methods used in this study);

– among the seven types of robots including AR700, AR900, AR1440, AR1730, AR2010, MA3120 and VA1400 II, MA3120 is identified as the best option;

– in addition to the six criteria for evaluating each type of robot that has been provided by the vendor as used in this study, buyers should be provided with other important criteria for evaluating robots such as the number of degrees of freedom of the robotic arm, robotic arm operating range, ability to control welding power supply, etc. At that time, the decision-making of multiple criteria to choose the best option must consider these criteria further. This is a job to do in the future in choosing robots.

The data normalization and weighting methods used in this study can only be applied when the criteria are in quantitative form. These methods cannot be applied when the criteria are in qualitative form such as ease of use, warranty coverage, customer preferences, etc. This is the limitation of this study. To overcome this limitation, methods such as CURLI, PIPRECIA can be used.

7. Conclusion

1. When using the MEREC method, the weights of the criteria from C1 to C6 are 0.2594, 0.2554, 0.0931, 0.1775, 0.2067, 0.0079, respectively. When using the ROC method, the weights of the criteria from C1 to C6 are 0.4083, 0.2417, 0.1583, 0.1028, 0.0611, 0.0278, respectively. If the RS method is used, the weights of criteria C1, C2, C3, C4, C5 and C6 are 0.2857, 0.2381, 0.1905, 0.1429, 0.0952 and 0.0476, respectively. Of course, when the EQUAL method is used, the weights of all criteria are equal.

2. The results of using two MCDM methods including MARCOS and PSI in the selection of a welding robot are presented. The ranking results of the two methods are shown in tables for evaluation. MARCOS and PSI methods have been reported to be quite suitable for MCDM problems for welding robot rating. The selection of the best alternative does not depend on the MCDM method as well as the criterion weight calculation method (at least for the methods used in this study). The best alternative, option MA3120, has been identified by all methods mentioned above.

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.

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Data availability

The manuscript has data included as electronic supplementary material.

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