Applied Engineering Letters **Vol.8, No.3, 131-138 (2023)** **e-ISSN: 2466-4847**

ENHANCING HANDHELD POLISHING MACHINE SELECTION: AN INTEGRATED APPROACH OF MARCOS METHODS AND WEIGHT DETERMINATION TECHNIQUES

UDC:621.923:519.816
Original scientific paper
https://doi.org/10.18485/aeletters.2023.8.3.5

Nguyen Xuan Truong[1], Aleksandar Ašonja[2], Do Duc Trung[1*]

[1]Faculty of Mechanical Engineering, Hanoi University of Industry, Hanoi City, 100000, Vietnam
[2]Faculty of Economics and Engineering Management, University Business Academy, Novi Sad, Serbia

Abstract:
The handheld polishing machine plays a pivotal role in enhancing the aesthetics of household products, making it a vital device. This research aims to identify the optimal option among the available types. Thirteen diverse handheld polishing machines were utilized for evaluation. Six key criteria were carefully chosen to assess each alternative, encompassing price, capacity, polishing disc diameter, polishing disc speed at idle, machine weight, and supplier warranty period. The relative importance of these criteria was determined using four distinct methods: Equal weighting, *RS (*Rank Sum*)* weighting, *ROC (*Rank Order Centroid*)* weighting, and Entropy weighting. The *MARCOS (*Measurement Alternatives and Ranking according to COmpromise Solution*)* method was employed to rank the alternatives. Remarkably, all four different weighting methods consistently led to the same conclusion, identifying the best and worst options.

ARTICLE HISTORY
Received: 1 June 2023
Revised: 3 September 2023
Accepted: 15 September 2023
Published: 30 September 2023

KEYWORDS
Selection of handheld polishing machine, MARCOS method, Equal weighting, RS weighting, ROC weighting, Entropy weighting

1. INTRODUCTION

Handheld polishing machines find extensive applications in the handicraft industry. They serve as portable tools capable of smoothing, polishing, and refining various materials, including wooden beds, chair legs, walls, and more, thereby significantly enhancing the overall aesthetics of the products. When purchasing a polishing machine, it becomes imperative to carefully evaluate multiple parameters such as machine power, polishing disc diameter, machine weight, and price. However, for buyers, selecting the most suitable product from a wide array of available types can be daunting and intricate. The complexity arises from the vast diversity of machines in the market, each offering diverse specifications. Addressing this challenge, which involves considering multiple parameters to identify the optimal choice among several options, is known as Multi-Criteria Decision Making (*MCDM*) [1].

When utilizing *MCDM* methods to prioritize options, three key factors significantly influencing the ranking are the *MCDM* method itself, the data normalization approach, and the method employed to determine weights for criteria [1]. Among these methods, *MARCOS* stands out as an *MCDM* technique that seamlessly integrates with various data normalization methods [2]. Remarkably, the *MARCOS* method diminishes the reliance on predefined weights for criteria when identifying the optimal option [3]. As a result of these inherent advantages, the *MARCOS* method has witnessed widespread application in diverse domains in recent times. Noteworthy examples include its utilization in selecting welding robots [4], opting for green logistics solutions [5], assessing the integration of Industry 4.0 technology in logistics activities [6], choosing suppliers in the healthcare supply chain during the Covid-19 period [7], ranking the efficiency of life insurance companies [8], evaluating health insurance companies during the

*CONTACT: D.D. Trung, e-mail: doductrung@haui.edu.vn

Covid-19 period [9], ranking cutting tools [10], selecting construction machinery for road infrastructure projects [11], ranking road traffic risk factors [12], evaluating the efficiency of trading companies in Serbia [13], ranking of fabrics containing recycled fibers [14], to decide on investment for a CGB (Community Group-Buying) in China [15], selecting sustainable suppliers [16], ranking of steel manufacturing companies in India [17], evaluating the effectiveness of using drones in logistics [18], ranking of electric vehicles [19], supplier selection for the steel manufacturing industry in India [20], hospital organizational structure selection [21] , ect.

This article pioneers the application of the *MARCOS* method for ranking handheld polishing machines. Part two of this article presents the ranking sequence of options by employing the *MARCOS* method.

To ensure a comprehensive outcome, the weights of the criteria will be determined using multiple distinct methods. The four weighting methods used to determine the weights are the Equal method, the *RS* method, the *ROC* method, and the Entropy method. The Equal method considers that all criteria are equally important. The *RS* and *ROC* methods consider the priority order of criteria, but the formulas in these two methods differ. Meanwhile, the Entropy method determines the weight values of criteria regardless of the decision maker’s perspective. The differences between these four weighting methods create a unique point for this article when these four methods are combined with the MARCOS method to rank handheld polishing machines. Additionally, part three outlines the formulas for calculating criteria weights using specific methods, while part four focuses on ranking handheld polishing machines. Ultimately, the conclusions drawn from this study serve as the final contribution to this research. The successful utilization of the MARCOS method in ascertaining the superior handheld polishing machine underscores its efficacy in navigating complex decision scenarios. Beyond its pivotal role in our equipment selection, MARCOS displays promise in guiding optimal choices across different domains, ensuring efficient and well-informed decision outcomes.

2. MARCOS METHOD

Perform the following seven steps to rank options according to the *MARCOS* method [22]:

Step 1: The decision matrix is formulated following the guidelines outlined in equation (1).

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ x_{21} & \cdots & x_{2n} \\ \vdots & \cdots & \vdots \\ x_{mn} & \cdots & x_{mn} \end{bmatrix} \tag{1}$$

In which: *m*, *n*, and x_{mn} respectively represent the number of alternatives, the number of criteria, and the value of criterion *n* for alternative *m*.

Step 2: Let *C* denote the criteria of the type "*the smaller, the better*" and *B* denote the criteria of the type "*the larger, the better*". Building an extended initial matrix by adding an ideal solution (*AI*) and the opposite solution to the ideal solution (*AAI*).

$$X = \begin{matrix} AAI \\ A_1 \\ A_2 \\ \vdots \\ A_m \\ AI \end{matrix} \begin{bmatrix} x_{aa1} & \cdots & x_{aan} \\ x_{11} & \cdots & x_{1n} \\ x_{21} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots \\ x_{m1} & \cdots & x_{mn} \\ x_{ai1} & \cdots & x_{ain} \end{bmatrix} \tag{2}$$

Where:

$AAI = min\ (x_{ij})$; *i* = 1-*m*; *j* = 1-*n* $\quad if\ j\ \in B$

$AAI\ = max\ (x_{ij})$; *i* = 1-*m*; *j* = 1-*n* $\quad if\ j\ \in C$

$AI = max\ (x_{ij})$; *i* = 1-*m*; *j* = 1-*n* $\quad if\ j\ \in B$

$AI = min\ (x_{ij})$; *i* = 1-*m*; *j* = 1-*n* $\quad if\ j\ \in C$

Step 3: The data normalization is carried out using two formulas (3) and (4).

$$n_{ij} = \frac{x_{AI}}{x_{ij}} \qquad if\ j\ \in C \tag{3}$$

$$n_{ij} = \frac{x_{ij}}{x_{AI}} \qquad if\ j\ \in B \tag{4}$$

Step 4: Let w_j represent the weight of criterion j. The normalized value, taking into account the weights of the criteria, is calculated using formula (5).

$$v_{ij} = n_{ij} \cdot w_j \tag{5}$$

Step 5: Calculate two quantities K_i^+ and K_i^- using their respective formulas (6) and (7).

$$K_i^- = \frac{S_i}{S_{AAI}} \tag{6}$$

$$K_i^+ = \frac{S_i}{S_{AI}} \tag{7}$$

Where S_i, S_{AAI}, and S_{AI} respectively represent the sum of values for v_{ij}, x_{aai}, and x_{ai}, with *i* = 1, 2, ..., *m*.

Step 6: Calculate two quantities $f(K_i^+)$ and $f(K_i^-)$ using their respective formulas (8) and (9).

$$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^i} \tag{8}$$

$$f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^i} \tag{9}$$

Step 7: Formula (10) is utilized to calculate the scores for each alternative.

$$f(K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1 - f(K_i^+)}{f(K_i^+)} + \frac{1 - f(K_i^-)}{f(K_i^-)}} \quad (10)$$

The ranking of alternatives is determined based on the decreasing order of their scores.

3. THE WEIGHT DETERMINATION METHODS USED

Three methods for weight determination, namely the Equal weight method, the *ROC* weight method, and the *RS* weight method are employed to calculate the weights of the criteria based on their corresponding formulas (11), (12), and (13). These methods are straightforward, each employing a single formula [23].

$$w_j = \frac{1}{n} \quad (11)$$

$$w_j = \frac{1}{n}\sum_{k=i}^{n}\frac{1}{k} \quad (12)$$

$$w_j = \frac{2\,(n + 1 - k)}{n(n + 1)} \quad (13)$$

In formulas (12) and (13), k is the order of criterion j after the criteria have been arranged in descending priority order, $k = 1\text{-}n$.

Three formulas, (14), (15), and (16), are utilized to calculate the criteria weights using the Entropy weighting method, which is highly recommended [24].

$$n_{ij} = \frac{y_{ij}}{m + \sum_{i=1}^{m} y_{ij}^2} \quad (14)$$

$$e_j = \sum_{i=1}^{m}\left[n_{ij} \times \ln(n_{ij})\right] - \left(1 - \sum_{i=1}^{m} n_{ij}\right) \times \ln\left(1 - \sum_{i=1}^{m} n_{ij}\right) \quad (15)$$

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{m}(1 - e_j)} \quad (16)$$

4. SELECTION OF HANDHELD POLISHING MACHINES USING THE MARCOS METHOD

4.1. Types of handheld polishing machines

Seven popular types of handheld polishing machines available in the Vietnamese market are denoted as *PM1*, *PM2*,..., *PM7*. Based on information provided by the supplier, the author of this article has identified six criteria, labeled from *C1* to *C6*, to characterize each machine [16]. The meaning and unit of measurement for each criterion are as follows:

C1: Selling price (VND) in thousand VND,
C2: Power (W),
C3: Polishing disc diameter (mm),
C4: No-load speed (rev/min),
C5: Weight (kg),
C6: Warranty period (month).

Although the supplier's website may contain other criteria (e.g., power supply voltage, length of power cord, etc.), these criteria have identical values across all options, making them unnecessary for ranking the alternatives.

According to the data in Table 1, *C1* is best for *PM8*, *C2* is best for *PM5*, *C3* is best at 180 mm (corresponding to *PM1*, *PM2*, *PM3*, *PM4*, *PM5*, *PM6*, *PM7*, *PM10*), *C4* is best for *PM9*, *C5* is best for *PM11*, and *C6* is best at 12 months (corresponding to machines *PM2*, *PM7* and *PM12*). Hence, there is no machine that fulfills all six criteria with the best value simultaneously. However, among the available options, there is a single type of machine that excels in all six criteria, making it the "best" choice overall. To identify this optimal option, the *MARCOS* method will be employed. Nevertheless, before proceeding with the selection process, the first essential step is to determine the weights for the criteria.

4.2. Determine the weights for the criteria

The formulas from part 3 have been utilized to ascertain the weights of the criteria through four distinct methods. In particular, to apply the two weighting methods *RS* and *ROC*, assume the priority order of the criteria is descending in the order *C1*, *C2*, *C3*, *C4*, *C5*, *C6*. The resulting data has been summarized in Table 2.

4.3. Options ranking

The decision matrix represents the data table for handheld polishing machines (Table 1).

The expanded initial matrix was constructed following formula (2) and is presented in Table 3. The normalization matrix was created using formulas (3) and (4), and the outcomes were summarized in Table 4. Formula (5) was utilized to calculate the normalized value, considering the criteria weights. Initially, the weight set for the criteria was determined using the Equal weight method, and the outcomes were compiled in Table 5.

Table 1. Types of hand-held polishing machines [25]

Code	C1	C2	C3	C4	C5	C6
PM1	5230	1200	180	3200	3.5	6
PM2	5175	1200	180	3000	3	12
PM3	1500	1020	180	3600	3.6	6
PM4	4832	1200	180	3000	3	6
PM5	1250	2000	180	3000	3	6
PM6	1200	1400	180	3200	3.4	6
PM7	5021	900	180	2000	2.2	12
PM8	390	600	150	4500	1	6
PM9	1171	240	125	24000	1.1	6
PM10	3450	1250	180	3000	2.8	6
PM11	1750	1400	150	3500	4.7	6
PM12	1925	440	150	4700	1.2	12
PM13	1400	240	125	12000	1.2	6

Table 2. Weights of the criteria

Weight method	C1	C2	C3	C4	C5	C6
Equal	1/6	1/6	1/6	1/6	1/6	1/6
RS	0.2857	0.2381	0.1905	0.1429	0.0952	0.0476
ROC	0.4083	0.2417	0.1583	0.1028	0.0611	0.0278
Entropy	0.1386	0.1392	0.1434	0.1384	0.2463	0.1942

Table 3. Extended Initial Matrix

Code	C1	C2	C3	C4	C5	C6
AAI	5230	240	125	2000	1	6
PM1	5230	1200	180	3200	3.5	6
PM2	5175	1200	180	3000	3	12
PM3	1500	1020	180	3600	3.6	6
PM4	4832	1200	180	3000	3	6
PM5	1250	2000	180	3000	3	6
PM6	1200	1400	180	3200	3.4	6
PM7	5021	900	180	2000	2.2	12
PM8	390	600	150	4500	1	6
PM9	1171	240	125	24000	1.1	6
PM10	3450	1250	180	3000	2.8	6
PM11	1750	1400	150	3500	4.7	6
PM12	1925	440	150	4700	1.2	12
PM13	1400	240	125	12000	1.2	6
AI	390	2000	180	24000	4.7	12

Table 4. Normalization matrix

Code	C1	C2	C3	C4	C5	C6
AAI	0.0746	0.1200	1.4400	0.0833	4.7000	0.5000
PM1	0.0746	0.6000	1.0000	0.1333	1.3429	0.5000
PM2	0.0754	0.6000	1.0000	0.1250	1.5667	1.0000
PM3	0.2600	0.5100	1.0000	0.1500	1.3056	0.5000
PM4	0.0807	0.6000	1.0000	0.1250	1.5667	0.5000
PM5	0.3120	1.0000	1.0000	0.1250	1.5667	0.5000
PM6	0.3250	0.7000	1.0000	0.1333	1.3824	0.5000
PM7	0.0777	0.4500	1.0000	0.0833	2.1364	1.0000
PM8	1.0000	0.3000	1.2000	0.1875	4.7000	0.5000
PM9	0.3330	0.1200	1.4400	1.0000	4.2727	0.5000
PM10	0.1130	0.6250	1.0000	0.1250	1.6786	0.5000
PM11	0.2229	0.7000	1.2000	0.1458	1.0000	0.5000
PM12	0.2026	0.2200	1.2000	0.1958	3.9167	1.0000
PM13	0.2786	0.1200	1.4400	0.5000	3.9167	0.5000
AI	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table 5. Normalized values considering the weights of the criteria

Code	C1	C2	C3	C4	C5	C6
AAI	0.0124	0.0200	0.2400	0.0139	0.7833	0.0833
PM1	0.0124	0.1000	0.1667	0.0222	0.2238	0.0833
PM2	0.0126	0.1000	0.1667	0.0208	0.2611	0.1667
PM3	0.0433	0.0850	0.1667	0.0250	0.2176	0.0833
PM4	0.0135	0.1000	0.1667	0.0208	0.2611	0.0833
PM5	0.0520	0.1667	0.1667	0.0208	0.2611	0.0833
PM6	0.0542	0.1167	0.1667	0.0222	0.2304	0.0833
PM7	0.0129	0.0750	0.1667	0.0139	0.3561	0.1667
PM8	0.1667	0.0500	0.2000	0.0313	0.7833	0.0833
PM9	0.0555	0.0200	0.2400	0.1667	0.7121	0.0833
PM10	0.0188	0.1042	0.1667	0.0208	0.2798	0.0833
PM11	0.0371	0.1167	0.2000	0.0243	0.1667	0.0833
PM12	0.0338	0.0367	0.2000	0.0326	0.6528	0.1667
PM13	0.0464	0.0200	0.2400	0.0833	0.6528	0.0833
AI	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667

The parameters K_i^-, K_i^+, $f(K_i^+)$, $f(K_i^-)$ and $f(K_i)$ are calculated using their respective formulas (6), (7), (8), (9), and (10), and the results are presented in Table 6. Additionally, this table includes the rankings of the alternatives based on their value.

Once the weights of the criteria are determined using the remaining three methods, the ranking of the options is carried out in a similar manner. Table 7 displays the ranking results of the options when the criteria weights are calculated using different methods.

According to the data in Table 7, the rankings of the options are different when different weighting methods are used to calculate the weights for the criteria. This is similar to the statement mentioned in recently published documents [26, 27]. However, the 1st, 12th, and 13th-ranked alternatives are exactly the same using the four different weighting methods. This level of agreement indicates a high confidence level in the ranking results of these options. Notably, the MP8 machine ranks as the worst option, while the *PM1* machine emerges as the best option.

Table 6. Some parameters in the MARCOS method and ranking of alternatives

Code	K_i^-	K_i^+	$f(K_i^+)$	$f(K_i^-)$	$f(K_i)$	Rank
PM1	8.00×10^{-5}	2.28×10^{-5}	0.2224	0.7776	2.15×10^{-5}	1
PM2	9.57×10-5	2.73×10^{-5}	0.2224	0.7776	2.57×10^{-5}	7
PM3	8.17×10^{-5}	2.33×10^{-5}	0.2224	0.7776	2.20×10^{-5}	2
PM4	8.49×10^{-5}	2.42×10^{-5}	0.2224	0.7776	2.28×10^{-5}	4
PM5	9.87×10^{-5}	2.82×10^{-5}	0.2224	0.7776	2.65×10^{-5}	8
PM6	8.86×10^{-5}	2.53×10^{-5}	0.2224	0.7776	2.38×10^{-5}	5
PM7	1.04×10^{-5}	2.97×10^{-5}	0.2224	0.7776	2.80×10^{-5}	9
PM8	1.73×10^{-5}	4.94×10^{-5}	0.2224	0.7776	4.65×10^{-5}	13
PM9	1.68×10^{-5}	4.80×10^{-5}	0.2224	0.7776	4.52×10^{-5}	12
PM10	8.86×10^{-5}	2.53×10^{-5}	0.2224	0.7776	2.38×10^{-5}	6
PM11	8.26×10^{-5}	2.36×10^{-5}	0.2224	0.7776	2.22×10^{-5}	3
PM12	1.48×10^{-5}	4.22×10^{-5}	0.2224	0.7776	3.97×10^{-5}	10
PM13	1.48×10^{-5}	4.23×10^{-5}	0.2224	0.7776	3.98×10^{-5}	11

Table 7. Ranking of handheld polishing machines

Code	Equal weight	RS weight	ROC weight	Entropy weight
PM1	1	1	1	1
PM2	7	4	4	8
PM3	2	3	6	3
PM4	4	2	2	4
PM5	8	9	10	7
PM6	5	8	8	5
PM7	9	6	3	9
PM8	13	13	13	13
PM9	12	12	12	12
PM10	6	5	5	6
PM11	3	7	7	2
PM12	10	10	9	11
PM13	11	11	11	10

CONCLUSIONS

The *MARCOS* method was applied in this study for the first time to rank handheld polishing machines. Four distinct methods were employed to determine the criteria weights, aiming to derive the most comprehensive conclusions. Several key findings are as follows:

1. The best and worst options consistently align when the criteria weights are determined using the four different methods. This reaffirms the remarkable advantages of the *MARCOS* method over other Multi-Criteria Decision Making (*MCDM*) techniques. This also makes a recommendation that the *MARCOS* method should be used to rank options in other areas.

2. Among the thirteen types of handheld polishing machines, *PM1* is identified as the top-performing option. The optimal machine exhibits a selling price of 5230 VNDT, a power rating of 1200 W, a polishing disc diameter of 180 mm, a no-load speed of 3200 rev/min, a weight of 3.5 kg, and a warranty period of 6 months.

3. Choosing a handheld polishing machine will become more comprehensive if additional criteria such as convenience and safety of use, power consumption, maintenance costs, etc. are considered. This task needs to be carried out in the near future.

4. The weight values of the criteria will change if the priority order of the criteria changes when using the *RS* and *ROC* methods. This issue depends on the decision maker's perspective. Then how will the rankings of handheld polishing machines change? This question also needs to be answered in the near future.

REFERENCES

[1] C. Zopounidis, M. Doumpos, Multiple Criteria Decision Making - Applications in Management and Engineering. *Springer*, 2017. https://doi.org/10.1007/978-3-319-39292-9

[2] D.D. Trung, Development of data normalization methods for multi-criteria decision making: applying for MARCOS method. *Manufacturing Review*, 9(22), 2022: 1-15. https://doi.org/10.1051/mfreview/2022019

[3] D.D. Trung, Multi-criteria decision making under the MARCOS method and the weighting methods: applied to milling, grinding and turning processes. *Manufacturing Review*, 9(3), 2022: 1-13. https://doi.org/10.1051/mfreview/2022003

[4] N.H. Son, T.T. Hieu, Selection of welding robot by multi-criteria decisionmaking method. *Eastern-European Journal of Enterprise Technologies*, 121(3), 2023: 66-72. https://doi.org/10.15587/1729-4061.2023.269026

[5] N.A. Osintsev, Multi-Criteria Decision-Making Methods in Green Logistics. *World of Transport and Transportation*, 19(5), 2021: 231-240. https://doi.org/10.30932/1992-3252-2021-19-5-13

[6] S. Miskic, S. Tadic, Z. Stevic, M. Krstic, V. Roso, A Novel Hybrid Model for the Evaluation of Industry 4.0 Technologies' Applicability in Logistics Centers. *Journal of Mathematics*, 2023, 2023: 3532862. https://doi.org/10.1155/2023/3532862

[7] D. Pamucar, A.E. Torkayesh, S. Biswas, Supplier selection in healthcare supply chain management during the COVID-19 pandemic: a novel fuzzy rough decision-making approach. *Annals of Operations Research*, 328, 2023: 979-1019. https://doi.org/10.1007/s10479-022-04529-2

[8] A. Ghosh, A. Sarkar, M. Dey, B. Guha, S. Jana, N. Ghorui, Analyzing Efficiency of Indian Life Insurance Companies using DEA and SEM. *Turkish Journal of Computer and Mathematics Education*, 12(12), 2021: 3897-3919.

[9] F. Ecer, D. Pamucar, MARCOS technique under intuitionistic fuzzy environment for determining the COVID-19 pandemic performance of insurance companies in terms of healthcare services. *Applied Soft Computing Journal*, 104, 2021: 107199. https://doi.org/10.1016/j.asoc.2021.107199

[10] D.D. Trung, N.H. Son, T.T. Hieu, V.T.N. Uyen, DOE-MARCOS: a new approach to multi-criteria decision making. *Journal of Applied Engineering Science*, 21(1) 2023: 263-274. https://doi.org/10.5937/jaes0-40221

[11] B. Matic, M. Marinkovic, S. Jovanovic, S. Sremac, Z. Stevic, Intelligent Novel IMF D-SWARA—Rough MARCOS Algorithm for Selection Construction Machinery for Sustainable Construction of Road Infrastructure. *Buildings*, 12(7), 2022: 1059. https://doi.org/10.3390/buildings12071059

[12] M. Stankovic, Z. Stevic, D. K. Das, M. Subotic, D. Pamucar, A New Fuzzy MARCOS Method for Road Traffic Risk Analysis. *Mathematics*, 8(3), 2020: 457. https://doi.org/10.3390/math8030457

[13] R. Lukic, Application of MARCOS method in evaluation of efficiency of trade companies in Serbia. *Ekonomski pogledi*, 24(1), 2022: 1-14. https://doi.org/10.5937/ep24-38921

[14] D.T. Birkocak, E.Acar, A.Ç. Bakadur, B. Ütebay, A. Özdağoğlu An Application of the MARCOS Method Within the Framework of Sustainability to Determine the Optimum Recycled Fibre-Containing Fabric. *Fibers and Polymers*, 24, 2023: 2595–2608. https://doi.org/10.1007/s12221-023-00197-6

[15] H. Wang, K. Ullah, T-spherical uncertain linguistic MARCOS method based on generalized distance and Heronian mean for multi-attribute group decision-making with unknown weight information. *Complex & Intelligent Systems*, 9, 2023: 1837-1869. https://doi.org/10.1007/s40747-022-00862-y

[16] C.-N. Wang, T.T.T. Nguyen, T.-T. Dang, N.-A.-T. Nguyen, A Hybrid OPA and Fuzzy MARCOS Methodology for Sustainable Supplier Selection with Technology 4.0 Evaluation. *Processes*, 10(11), 2022: 2351. https://doi.org/10.3390/pr10112351

[17] R. Dwivedi, K. Prasad, P.K. Jha, S. Singh, An Integrated CRITIC-MARCOS Technique for Analysing the Performance of Steel Industry. In K. Kalita, R. Ghadai, X. Gao (Eds.). *Data-Driven Optimization of Manufacturing Processes,* 2021: 115-127. htps://doi.org/10.4018/978-1-7998-7206-1.ch008

[18] M. Kovač, S. Tadić, M. Krstić, M.B. Bouraima, Novel Spherical Fuzzy MARCOS Method for Assessment of Drone-Based City Logistics Concepts. *Complexity*, 2021, 2021: 2374955. https://doi.org/10.1155/2021/2374955

[19] E. Çakır, M.A. Taş, Z. Ulukan, Neutrosophic Fuzzy MARCOS Approach for Sustainable Hybrid Electric Vehicle Assessment. *2021 IEEE International Conference on Systems*, Man, and Cybernetics, 7-20 October 2021, Melbourne, Australia 2022, 21456497. https://doi.org/10.1109/SMC52423.2021.9659199

[20] S. Chakraborty, R. Chattopadhyay, S. Chakraborty, An integrated D-MARCOS method for supplier selection in an iron and steel industry. *Decision Making: Applications in Management and Engineering*, 3(2), 2020: 49-69. https://doi.org/10.31181/dmame2003049c

[21] M. Khosravi, A. Haqbin, Z. Zare, P. Shojaei, Selecting the most suitable organizational structure for hospitals: an integrated fuzzy FUCOM-MARCOS method. *Cost Effectiveness and Resource Allocation*, 20, 2022: 29. https://doi.org/10.1186/s12962-022-00362-3

[22] Z. Stevic, D. Pamucar, A. Puska, P. Chatterjee, Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement Alternatives and Ranking according to COmpromise Solution (MARCOS). *Computers & Industrial Engineering*, 140, 2020: 106231. https://doi.org/10.1016/j.cie.2019.106231

[23] D.D. Trung, Application of TOPSIS and PIV methods for multi-criteria decision making in hard turning process. *Journal of Machine Engineering*, 21(4), 2021: 57-71. https://doi.org/10.36897/jme/142599

[24] D.D. Trung, H.X. Thinh, A multi-criteria decision-making in turning process using the MAIRCA, EAMR, MARCOS and TOPSIS methods: A comparative study. *Advances in Production Engineering & Management*, 16(4), 2021: 443-456. https://doi.org/10.14743/apem2021.4.412

[25] https://dienmayhaianh.vn/san-pham/may-danh-bong-c340.html (Accessed: 22 May 2023).

[26] D.N. Markatos, S. Malefaki, S.G. Pantelakis, Sensitivity Analysis of a Hybrid MCDM Model for Sustainability Assessment-An Example from the Aviation Industry. *Aerospace,* 10(4), 2023: 385. https://doi.org/10.3390/aerospace10040385

[27] H.A. Dağıstanlı, An Integrated Fuzzy MCDM and Trend Analysis Approach for Financial Performance Evaluation of Energy Companies in Borsa Istanbul Sustainability Index. *Journal of Soft Computing and Decision Analytics*, 1(1), 2023: 39-49. https://doi.org/10.31181/jscda1120233