Measuring performances through multiplicative functions by modifying the MEREC method: MEREC-G and MEREC-H

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Abstract

Purpose – This study aims to apply new modifications by changing the nonlinear logarithmic calculation steps in the method based on the removal effects of criteria (MEREC) method. Geometric and harmonic mean from multiplicative functions is used for the modifications made while extracting the effects of the criteria on the overall performance one by one. Instead of the nonlinear logarithmic measure used in the MEREC method, it is desired to obtain results that are closer to the mean and have a lower standard deviation.

Design/methodology/approach – The MEREC method is based on the removal effects of the criteria on the overall performance. The method uses a logarithmic measure with a nonlinear function. MEREC-G using geometric mean and MEREC-H using harmonic mean are introduced in this study. The authors compared the MEREC method, its modifications and some other objective weight determination methods.

Findings – MEREC-G and MEREC-H variants, which are modifications of the MEREC method, are shown to be effective in determining the objective weights of the criteria. Findings of the MEREC-G and MEREC-H variants are more convenient, simpler, more reasonable, closer to the mean and have fewer deviations. It was determined that the MEREC-G variant gave more compatible findings with the entropy method.

Practical implications – Decision-making can occur at any time in any area of life. There are various criteria and alternatives for decision-making. In multi-criteria decision-making (MCDM) models, it is a very important distinction to determine the criteria weights for the selection/ranking of the alternatives. The MEREC method can be used to find more reasonable or average results than other weight determination methods such as entropy. It can be expected that the MEREC method will be more used in daily life problems and various areas.

Originality/value – Objective weight determination methods evaluate the weights of the criteria according to the scores of the determined alternatives. In this study, the MEREC method, which is an objective weight determination method, has been expanded. Although a nonlinear measurement model is used in the literature, the contribution was made in this study by using multiplicative functions. As an important originality, the authors demonstrated the effect of removing criteria in the MEREC method in a sensitivity analysis by actually removing the alternatives one by one from the model.

Keywords MEREC, MEREC-G, MEREC-H, Objective methods

Paper type Research paper

1. Introduction

Multi-criteria decision-making (MCDM) methods supply suitable solutions as a result of the existing criteria in different application areas. Criteria weights determination methods differ from each other due to the diverse mathematical approaches they use, yet they may be used for the same purpose. Particularly in the last two decades, various criteria determination methods have so many applications in almost every research area where more than one

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criterion exists in the performance evaluation of attributes (Pekkaya and Keleş, 2022, p. 6). New MCDM methods are being introduced at a dizzying pace. There must be a problem and multiple attributes to be able to make a decision. The decision problem is solved according to criteria based on the available alternatives. Determination of criteria weight is becoming an important problem (Keleş, 2022a, p. 153). The presence of subjective judgments and irrational statements in the information used to create the initial matrix complicates the decision-making. To objectify/rationalize the decision-making process, researchers strive to create new methods that enable objective processing of inaccuracies/subjectivity in information (Kaya *et al.*, 2022, p. 65). Methods for determining criteria weights in MCDM models have been the subject of scientific research for many years. Various methods such as the objective, subjective and integrated have been developed. Subjective weighting techniques are often problematic due to the need for truly expert knowledge in the field to accurately assign importance to criteria. Therefore, objective weighting techniques have a high potential in determining criteria weights (Bączkiewicz and Wątróbski, 2022, p. 61). The preferences of the decision-makers have no role in determining the criteria weights in objective weight determination methods. When the number of criteria increases, the disadvantage of not being efficient enough and decreasing the accuracy of the preferences is eliminated by using objective methods and thus producing criteria weights a certain computational process based on the initial data/decision matrix (Keshavarz-Ghorabaee *et al.*, 2021). Objective methods help calculate the importance of criteria through a statistical evaluation of the data in the decision matrix. Objective methods give reproducible results and can be used when there is difficulty in obtaining expert views (Bączkiewicz and Wątróbski, 2022, p. 62). One of the methods for determining objective weight is the MEREC method, which was introduced to the literature by Keshavarz-Ghorabaee *et al.*, very recently, in 2021. The entropy method, criteria importance through inter-criteria correlation (CRITIC) method, criterion impact loss (CILOS) method, logarithmic percentage change-driven objective weighting (LOPCOW) method and standard deviation method are well-known other exemplary objective weighting methods.

The determination of the weights of the criteria in MCDM has been carried out for many years with relatively more comprehensive and difficult-to-apply methods such as the analytic hierarchy process (AHP) method, according to the opinions of decision-makers. Determining the weights of the criteria by using decision matrix elements according to the alternatives rather than the views of the decision maker is very old. As an example, the entropy method is a relatively former method, introduced in 1948, and the CRITIC method was introduced in the literature in 1995. Especially in recent years, the introduction of the MEREC method in 2021 and the LOPCOW method in 2022 into the literature to determine the objective criteria weights resulted from the need to solve the problems more objectively.

The working principle of the objective methods is based on the evaluation of the scores of the previously determined alternatives according to the criteria, in contrast to the disadvantages of the subjective methods based on limited/biased/complex/emotional/subjective judgments. In general, the determination of the weights of the criteria is based on the following stages: (1) determining the alternatives and criteria related to the problem and forming the decision matrix, (2) normalizing the decision matrix, (3) comparing the criteria with the alternatives and (4) evaluating the alternatives/criteria according to the total performance and obtaining the criteria weights. The third step is the focus of this study. Based on the removal of the effects of the criteria on the overall performance one by one. The MEREC method was introduced to the literature as an objective criteria weight determination method by Keshavarz-Ghorabaee *et al.* (2021). In the third step of the MEREC method, a nonlinear logarithmic measure is used to compare the criteria.

The research questions this study tries to answer are as follows:

(1) How can the MEREC method be improved and made simpler?

(2) How can the MEREC method be presented from a more effective perspective?

(3) How can the logarithmic measurement function of the MEREC method be removed?

The motivation of this study is essentially the Keshavarz-Ghorabaee *et al.* study's recommendations to state that multiplicative functions can be used instead of logarithmic measures to measure alternative performances. Another motivation for the study is that no one has proposed into the nature of the MEREC method calculations, until now. To handle various decision-making problems, several authors have focused their attention on using the new MEREC method in their research, but not on its development. In this study, considering that there is a research gap, it is investigated to question the nature/structure of the MEREC method with an innovative perspective. This study aims to apply new modifications by changing the nonlinear logarithmic calculation steps in the MEREC method. MEREC-G using geometric mean and MEREC-H using harmonic mean are introduced in this study. In addition, a large literature review of studies using the MEREC method was conducted.

The rest of the paper is organized as follows. Section 2 introduces the literature belonging to the MEREC method and ensures a critical perspective. Section 3 describes the MEREC method and presents its modifications, namely MEREC-G and MEREC-H. Section 4 presents the results of the systematically studied and compared examples with MEREC, MEREC-G, MEREC-H and some other objective weight methods. Section 5 expounds on its contribution by explaining the practical and theoretical implications of the study. Section 6 provides the overall results from this study, with suggestions for future research about the subject.

2. Literature review for the MEREC method

The MEREC method was developed by Keshavarz-Ghorabaee *et al.* in early 2021. It is a completely new MCDM method that gives more precise and accurate results. It was proven more efficient objective weighting tool than CRITIC and entropy weighting methods (Goswami *et al.*, 2022, pp. 1154–1155). This method utilizes each criterion's removal effect on the estimation of alternatives to obtain the criteria weights. The evaluation of an option based on removing the criterion which is considering the deviations is a new concept in determining the criteria weights (Mishra *et al.*, 2022a, p. 24414). A criterion has an immense weight when its removal leads to a higher impact on alternatives' total performances. This perspective not only determines the objective weight of each criterion but may also make it easier for decision-makers to exclude certain criteria from the decision-making procedure (Rani *et al.*, 2022, p. 2615; Kaya *et al.*, 2022, p. 64). The MEREC uses an exclusion perspective and removal effects rather than the inclusion perspective, which is the basis of other objective weighting methods, to obtain objective criteria weights (Keshavarz-Ghorabaee, 2021, p. 5).

Nicolalde *et al.* (2022) stated that the MEREC method is a novel method based on the removal effects of criteria and shows an interesting methodology. Ease of understanding and computation and a robust mathematical background can be lined up as the major advantages of the MEREC method (Kaya *et al.*, 2022, p. 4). The MEREC weights the criteria as an objective method proved to be reliable over a more traditional method as entropy and as a novel method applicable to be used for decision-making problems (Nicolalde *et al.*, 2022, p. 12). The calculation process is clear, logical and methodical (Simić *et al.*, 2022a, p. 2). Although it has been a very short time since the method was introduced to the literature, it has been accepted very quickly and has found application in many different fields. The MEREC method is used to determine the weights for attributes/criteria in literature. Studies using the MEREC method are presented (See Table 1).

Studies in the literature in a short time are remarkable. 24 studies were found. The MEREC method has been accepted in the literature in a short time and has been used by many researchers. In addition, it can be said that it is used to find criteria weights in many fields such as distribution center and hospital location, cloud service provider, banking sector,

Researcher/s/Year	Method/s	Research subjects
Keshavarz-Ghorabaee *et al.* (2021)	MEREC, CRITIC, entropy, standard deviation	Selecting the location for new distribution centers
Trung and Thinh (2021)	Entropy, MEREC, MAIRCA, EAMR, MARCOS, TOPSIS	Experiments in the turning process
Popović *et al.* (2021)	MEREC, WISP	Cloud service selection
Rani *et al.* (2022)	Fermatean Fuzzy (FF)-MEREC-ARAS	Waste treatment technology selection
Ahmad *et al.* (2022)	MEREC, MARCOS	The effect of input variables on the performance of flexible manufacturing systems
Ecer and Pamucar (2022)	LOP-COW, DOBI, MEREC	An application in developing country banking sector
Ghosh and Bhattacharya (2022)	MEREC, CoCoSo	The impact of COVID-19 on the financial performance of the hospitality and tourism industries
Goswami *et al.* (2022)	MEREC, PIV	Selection of a green renewable energy source
Hadi and Abdullah (2022)	MEREC, TOPSIS	Hospital location determination
Hezam *et al.* (2022)	IF-MEREC, RS-DNMA	Evaluating the alternative fuel vehicles with sustainability perspectives
Kaya *et al.* (2022)	MEREC, CRITIC, MARCOS	Evaluation of social factors within the circular economy concept
Marinković *et al.* (2022)	MEREC, CoCoSo	Application of wasted and recycled materials for the production of stabilized layers of road structures
Mishra *et al.* (2022a)	MEREC, MULTIMOORA	Low carbon tourism strategy assessment
Nguyen *et al.* (2022)	MARCOS, TOPSIS, MAIRCA, MEREC	The best alternative for the powder-mixed electrical discharge machining process
Nicolalde *et al.* (2022)	Entropy, MEREC, VIKOR, COPRAS, TOPSIS	Selection of a phase change material for energy storage regarding the thermal comfort in a vehicle
Panchagnula *et al.* (2023)	MEREC, mean weight, standard deviation, entropy, CRITIC, CoCoSo	Determination of the most suitable combination of cutting parameters with minimum material damages
Petrović *et al.* (2022)	F-AHP, F-PIPRECIA, F-FUCOM, entropy, CRITIC, MEREC, TOPSIS, RDMR-G	Optimal synthesis of loader drive mechanisms
Sapkota *et al.* (2022)	MEREC, VIKOR, MABAC, CoCoSo	Selection of quality hole produced by ultrasonic machining process
Simić *et al.* (2022a)	MEREC, CoCoSo	Adapting urban transport planning model
Toslak *et al.* (2022)	MEREC, WEDBA	Logistics firm performance evaluation
Ulutaş *et al.* (2022)	MEREC, WISP-S	Pallet truck selection
Yu *et al.* (2022)	BWM, MEREC, PIV	Offshore wind farm site selection
Shanmugasundar *et al.* (2022)	CODAS, COPRAS, CoCoSo, MABAC, VIKOR, MEREC	Selection of optimal spray-painting robot
Saha *et al.* (2022)	MEREC, SWARA	Composite cloud service selection

Table 1.
Literature review of studies using the MEREC method

energy sector and circular economy. However, it is still mostly used in the evaluation of criteria with quantitative values. In most of the studies, the MEREC method was used with different weight determination methods, and the results were compared. Rani *et al.* (2022), Simić *et al.* (2022a), Narayanamoorthy *et al.* (2022) and Kamali Saraji and Streimikiene (2023) extended the MEREC method to the Fermatean fuzzy environment, and then Simić *et al.* (2022b) and Mishra *et al.* (2022a) extended the MEREC to the neutrosophic number environment. In some studies (Hezam *et al.*, 2022; Mishra *et al.*, 2022b), the classical MEREC method was extended to the intuitionistic fuzzy (IF) subjective objective integrated approach, using the IF-MEREC and ranking sum (RF) methods. In later studies (Chaurasiya and Jain, 2022; Zhai *et al.*, 2022), the MEREC method was extended to the Pythagorean fuzzy (PF-MEREC) approach. Besides, Simić *et al.* (2022a) stated that the classic MEREC is missing in integration with other methods into a unique methodology, and MEREC may not be able to cope with a multi-level decision making hierarchy.

In this context, it should be noted that the easiest way used in many studies is to give equal weights to the criteria. However, in the MEREC method, Keshavarz-Ghorabaee *et al.* (2021) focus on determining the weights of each measurement, which is one of the most critical and complex processes in the evaluation process of MCDM problems. When a criterion has more variation, it is stated to have greater weight. In this method, a criterion has a greater weight when its removal leads to more effects on the alternatives' total performances. It is thought that the method will be highly accepted in terms of solution stages, clearness and applicability.

3. The MEREC method and modifications: MEREC-G and MEREC-H

The MEREC method is an objective weighting method used to extract the effect of each criterion on the overall performance of the alternatives to calculate criteria weights (Toslak *et al.*, 2022, p. 364). The MEREC calculated an objective weight for every criterion, presented the consequence effect and the weight derived from it and shows an objective weight that displays a different result but is acceptable since the importance of the criteria is determined by focusing on the exclusion perspective rather than the inclusion (Nicolalde *et al.*, 2022, p. 7). In the objective weighting methods, unlike the subjective weighting methods, the preferences of the decision-makers do not play a role in calculating the criteria weights. In the calculation stages of objective methods, the decision matrix containing the actual data of the criteria is used. A second weighting method is performed to show the accuracy of the method used, to compare the methods and to indicate that the most suitable one is used. However, the MEREC method allows more weight to be given to criteria with higher implications in solving the problem (Kaya *et al.*, 2022, p. 5; Nicolalde *et al.*, 2022, p. 4). The paths followed by the study are visually presented in Figure 1.

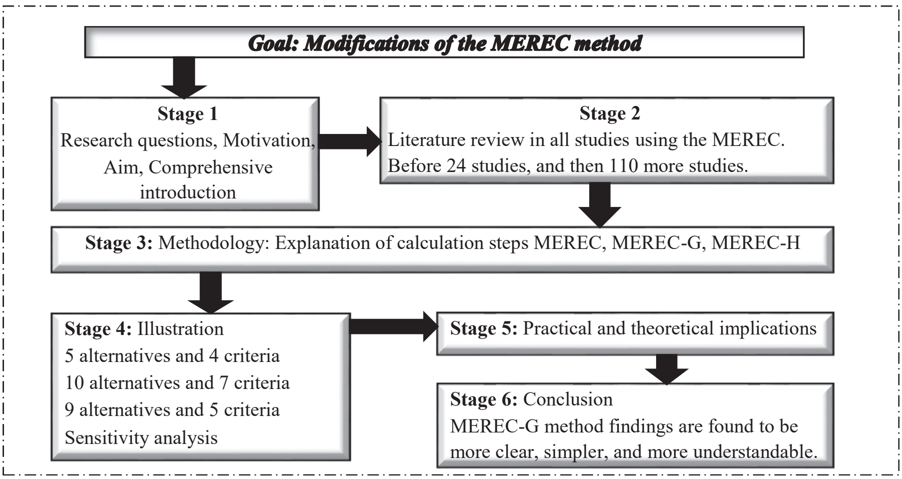

Figure 1.
The graphical abstract

This section presents the stages and modifications of the MEREC method as outlined in Step 3 of the graphical abstract. Keshavarz-Ghorabaee *et al.* (2021) stated that the solution steps of the method are carried out as follows.

Step 1: Performance evaluation decision matrix (X) is created. The values of each alternative for each criterion are shown. "n" is shown alternatives, and "m" is the criteria. The X_{ij} value shows the value of the "i" alternative in the "j" criterion. All values must be greater than zero.

$$X = [x_{ij}]_{mxn} \tag{1}$$

Step 2: Normalization is done (N). A different linear normalization is used to scale the elements of the decision matrix (X), apart from the other methods. The elements of the normalized matrix are shown by N_{ij}. Beneficial (B) represents the beneficial/maximum set of criteria, and nonbeneficial (NB) represents the non-beneficial/minimum set of criteria.

$$N_{ij} = \left\{ \frac{\min_{k} x_{kj}}{x_{ij}} \right\} if\ j \in B \text{ for beneficial/maximum set of criteria} \tag{2}$$

$$N_{ij} = \left\{ \frac{x_{ij}}{\max_{k} x_{kj}} \right\} if\ j \in NB \text{ for non} - \text{beneficial/ minimum set of criteria} \tag{3}$$

Step 3: Obtaining the overall performance. The overall performance value of the alternatives is calculated by applying a logarithm measure with equal criteria weights based on a nonlinear function. Thus, it can be ensured that smaller values give larger performance values than normalized values.

$$S_i = \ln\left(1 + \left(\frac{1}{m}\sum_{j} |\ln(N_{ij})|\right)\right) \tag{4}$$

Step 4: Obtaining the discrete overall performance. The changes in the performance value of the alternatives (S'_{ij}) are calculated by removing the value of each criterion.

$$S'_{ij} = \ln\left(1 + \left(\frac{1}{m}\sum_{k,k\neq j} |\ln(N_{ij})|\right)\right) \tag{5}$$

Step 5: Calculation of absolute deviations. The effect of removing a criterion (E_j) is calculated by summing the absolute deviations. The effect of removing on the criterion itself is measured. Absolute values should be observed.

$$E_j = \sum_{i} |S'_{ij} - S_i| \tag{6}$$

Step 6: Obtaining the final weights. The "E_j" values are normalized to determine the final weights of the criteria. The objective weight of each criterion (w_j) is calculated using the removal effects (E_j) of Step 5.

$$w_j = \frac{E_j}{\sum_K E_k} \tag{7}$$

The MEREC method uses a nonlinear logarithmic function in steps third and fourth to calculate the overall and removal effect of the performances of alternatives (Keshavarz-Ghorabaee *et al.*, 2021, p. 7; Simić *et al.*, 2022a, p. 2). However, based on the complexity, nonlinearity of logarithmic measurement and even suggestions that multiplicative functions can be used instead of logarithmic measures to measure alternative performances, new modifications have been considered. Without changing the other stages of the MEREC method, MEREC-G and MEREC-H variations are recommended considering that they are more clear, simple and understandable instead of the logarithmic functions suggested in the third and fourth stages. Using the MEREC-G and MEREC-H variants, the overall performances and the removal effect of each criterion can be more easily calculated. In this way, the evaluation of criteria that are closer to the mean may yield more reasonable results. Stages 3 and 4 can be calculated as follows.

Modified step 3: The overall performance value of the alternatives is calculated using the geometric and harmonic mean of the normalized matrix. Thus, a disadvantage of objective methods can be avoided. In other words, due to the fact that the highest and lowest values of the criteria are very discrete, high criteria weights can be prevented and performance values close to the average can be obtained. The third step can be calculated as follows. The calculation for the first row is also presented.

$$\mathrm{GM} = \sqrt[m]{\prod_{j=1}^{m} N_j} = \sqrt[m]{N_{11} \cdot N_{12} \cdot N_{13} \cdots N_m}, \text{m} = \text{number of criteria, N} = \text{normalized matrix} \tag{8}$$

$$\mathrm{HM} = \frac{m}{\sum_{j=1}^{m} \left(\frac{1}{N_j}\right)} = \frac{m}{\frac{1}{N_{11}} + \frac{1}{N_{12}} + \frac{1}{N_{13}} + \cdots \frac{1}{N_m}}, \text{'}i\text{' alternative, '}j\text{' criterion} \tag{9}$$

Modified step 4: The value of each criterion is removed from its effect on the total performance, and the changes in the total performance value of the alternatives are calculated. The fourth step can be calculated as follows. The calculation for the first row is also presented.

$$\mathrm{GM} = \sqrt[m]{\prod_{k,k\neq j}^{m} N_j} = \sqrt[m]{N_{12} \cdot N_{13} \cdots N_m} \tag{10}$$

k = is the number of remaining criteria in the calculation made by removing any criteria.

$$\mathrm{HM} = \frac{m}{\sum_{k,k\neq j}^{m} \left(\frac{1}{N_j}\right)} = \frac{m}{\frac{1}{N_{12}} + \frac{1}{N_{13}} + \cdots \frac{1}{N_m}} \tag{11}$$

It is thought that only the third and fourth steps can be modified without changing the other implementation steps, and the decision-making problems can be solved more simply and clearly.

4. Determining criteria weights by MEREC-G and MEREC-H method

The CRITIC method (Diakoulaki *et al.*, 1995; Jovčić and Průša, 2021; Ulutaş and Cengiz, 2018), entropy method (Lee *et al.*, 2012; Shemshadi *et al.*, 2011; Wang and Lee, 2009) and the MEREC method (Keshavarz-Ghorabaee *et al.*, 2021; Nicolalde *et al.*, 2022; Ulutaş *et al.*, 2022) were chosen among the objective weight determination methods in order to determine the criteria weights, perform the analyzes and compare. In this part, calculations and comparisons were made on the examples previously used by Keshavarz-Ghorabaee *et al.* (2021, pp. 9–11).

Example 1. The following example demonstrates calculations and comparisons on an example that takes into account the evaluation of five alternatives and four criteria. There are two beneficial criteria and two nonbeneficial criteria. In the applied example, the elements of the initial and normalized matrix are shown in Table 2.

After showing the initial decision matrix in Step 1 and the normalized matrix in Step 2, Steps 3, 4, 5 and 6 can be presented together, in Table 3.

Overall performance can be calculated by taking the geometric mean of the values of the criteria for each alternative from the values in the normalized matrix. Then, each criterion can be removed separately, and their effects on overall performance can be measured by taking the geometric mean. In the next steps, the difference is measured, and the weights are obtained. When the MEREC-G method is used in the calculations made on the example, the values found as a result of the calculation made by taking the geometric mean are presented in Table 4.

Then, overall performance can be calculated by taking the harmonic mean of the values of the criteria for each alternative from the values in the normalized matrix. After then, each criterion can be removed separately, and their effects on overall performance can be measured by taking the harmonic mean. In the next steps, the difference is measured, and the

Table 2. Initial and normalized decision matrix of Example 1

Step 1	C1 ε B	C2 ε B	C3 ε NB	C4 ε NB	Step 2	C1	C2	C3	C4
A1	450	8,000	54	145	A1	0.01	1.00	1.00	0.90
A2	10	9,100	2	160	A2	0.50	0.88	0.04	0.99
A3	100	8,200	31	153	A3	0.05	0.98	0.57	0.94
A4	220	9,300	1	162	A4	0.02	0.86	0.02	1.00
A5	5	8,400	23	158	A5	1.00	0.95	0.43	0.98

Table 3. Continuing stages of Example 1

Step 3		Step 4					Step 5		Step 6	
S1	0.767	A1	0.027	0.767	0.767	0.754	E1	1.709	w1	0.575
S2	0.709	A2	0.620	0.693	0.189	0.708	E2	0.042	w2	0.014
S3	0.646	A3	0.148	0.643	0.571	0.639	E3	1.193	w3	0.402
S4	1.092	A4	0.710	1.080	0.685	1.092	E4	0.027	w4	0.009
S5	0.208	A5	0.208	0.199	0.018	0.203	Total	2.970		

Table 4. Calculations according to the MEREC-G method

Step 3		Step 4					Step 5		Step 6	
S1	0.316	A1	0.964	0.215	0.215	0.223	E1	1.264	w1	0.429
S2	0.356	A2	0.318	0.263	0.757	0.253	E2	0.406	w2	0.138
S3	0.403	A3	0.809	0.300	0.358	0.304	E3	0.861	w3	0.292
S4	0.138	A4	0.252	0.075	0.269	0.071	E4	0.414	w4	0.141
S5	0.793	A5	0.734	0.746	0.976	0.740	Total	2.945		

weights are obtained. Moreover, when the MEREC-H variation is used in the calculations made on the same example, the values in the calculations made by taking the harmonic mean are presented in Table 5.

The calculation findings and correlations of the determined example are compared using different weight determination methods, and the results are presented in Table 6.

Pearson correlation analysis was performed since all samples were found to be suitable with normal distribution in Kolmogorov–Smirnov and Shapiro–Wilk tests. When the results of the CRITIC method were compared with other methods, negative correlations were found that were not significant. However, in the evaluation made for the MEREC method, very strong and significant correlations were found between entropy, MEREC-G and MEREC-H methods, respectively. Significant and very strong correlations were found between the MEREC-G, MEREC-H methods and the entropy method. The standard deviation of the criteria weights obtained by the MEREC-G method was found to be relatively lower than the MEREC and MEREC-H methods. Findings obtained according to different methods can also be shown graphically in Figure 2.

Step 3		Step 4					Step 5		Step 6	
S1	0.043	A1	0.962	0.033	0.033	0.033	E1	1.634	w1	0.581
S2	0.128	A2	0.103	0.100	0.723	0.100	E2	0.136	w2	0.049
S3	0.168	A3	0.784	0.132	0.136	0.132	E3	0.900	w3	0.320
S4	0.040	A4	0.053	0.030	0.065	0.030	E4	0.140	w4	0.050
S5	0.738	A5	0.678	0.686	0.976	0.682	Total	2.811		

Table 5. Calculations according to the MEREC-H method

	MEREC	MEREC-G	MEREC-H	CRITIC	Entropy	
w1	0.5752	0.4291	0.5813	0.2286	0.5569	
w2	0.0141	0.1379	0.0485	0.2407	0.0016	
w3	0.4015	0.2922	0.3201	0.2538	0.4406	
w4	0.0091	0.1406	0.0499	0.2767	0.0007	Std. deviation
MEREC	1					0.2843
MEREC-G	0.987	1				0.1395
MEREC-H	0.984	1.000	1			0.2552
CRITIC	−0.604	−0.643	−0.652	1		0.0206
Entropy	0.996	0.969	0.965	−0.565	1	0.2912

Table 6. Comparisons by different methods

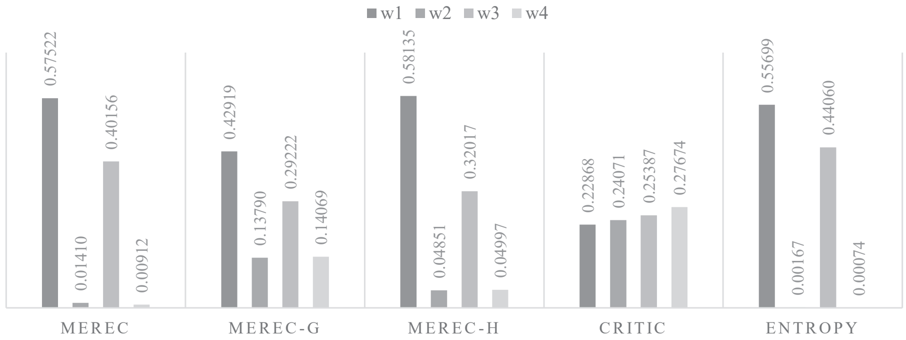

Figure 2. The weights of the methods of Example 1

The criteria weights obtained according to different methods can be viewed in more detail in the figure. Accordingly, it can be said that the findings of the MEREC and entropy methods are similar, the results of the CRITIC method are very close to each other and the MEREC-G method tends to present findings close to the average. For more, the results can be examined with another example.

Example 2. Calculations and comparisons are made on the example used earlier by Keshavarz-Ghorabaee *et al.* (2021, p. 11). In the example, 10 alternatives and seven criteria are used, three of which are beneficial criteria and four are nonbeneficial. The initial decision matrix is given in Table 7.

The computational findings of the second example are compared using different weight determination methods, and the results are presented in Table 8.

In the Shapiro–Wilk test, CRITIC and MEREC-G results were not found to be suitable for a normal distribution (but very close), and then Pearson correlation analysis was performed because other findings were suitable for a normal distribution. Similar to the former example, when the results of the CRITIC method were compared with other methods, nonsignificant negative correlations were found. Moreover, regarding this example, it can be said that Keshavarz-Ghorabaee *et al.* (2021, p. 11) found different criteria weights and did not follow the steps of the CRITIC method or by making a calculation mistake. Furthermore, positive, very strong and significant correlations between the entropy method and MEREC-H (r = 0.942;

Table 7. Initial decision matrix of Example 2

	C1-B	C2-B	C3-B	CD-NB	C5-NB	C6-NB	C7-NB
A1	23	264	2.37	0.05	167	8,900	8.71
A2	20	220	2.2	0.04	171	9,100	8.23
A3	17	231	1.98	0.15	192	10,800	9.91
A4	12	210	1.73	0.2	195	12,300	10.21
A5	15	243	2	0.14	187	12,600	9.34
A6	14	222	1.89	0.13	180	13,200	9.22
A7	21	262	2.43	0.06	160	10,300	8.93
A8	20	256	2.6	0.07	163	11,400	8.44
A9	19	266	2.1	0.06	157	11,200	9.04
A10	8	218	1.94	0.11	190	13,400	10.11

Note(s): B = beneficial criteria; NB = nonbeneficial criteria

Table 8. Comparisons by different methods of Example 2

	MEREC	MEREC-G	MEREC-H	CRITIC	Entropy	
w1	0.3244	0.2425	0.2292	0.1002	0.1989	
w2	0.0552	0.1008	0.0919	0.2002	0.0198	
w3	0.0864	0.0644	0.0692	0.1164	0.0397	
w4	0.3678	0.2866	0.3282	0.1231	0.6635	
w5	0.0445	0.1141	0.1016	0.1302	0.0161	
w6	0.0766	0.0786	0.0791	0.1949	0.0485	
w7	0.0451	0.1131	0.1008	0.1350	0.0135	Std. deviation
MEREC	1.000					0.1403
MEREC-G	0.947	1.000				0.0860
MEREC-H	0.953	0.985	1.000			0.0978
CRITIC	−0.523	−0.506	−0.471	1.000		0.0390
Entropy	0.873	0.871	0.942	−0.345	1.000	0.2386
	(p < 0.05)	(p > 0.05)	(p < 0.05)	(p > 0.05)	(p < 0.05)	

$p < 0.01$), MEREC ($r = 0.873$; $p < 0.05$) and MEREC-G ($r = 0.871$; $p < 0.05$) detected. The standard deviation of the criteria weights obtained by the MEREC-G method and then the MEREC-H method was found to be relatively lower than the MEREC method. Findings obtained according to different methods can also be shown graphically in Figure 3.

It is noteworthy that there is a large difference between the weights found by the entropy method. CRITIC method weights are similarly close to each other. On the other hand, it can be said that the MEREC-G method tends to present findings closer to the mean.

Example 3. A real-world problem for comparative analysis is borrowed from Keleş (2022b). So as to decide on the selection of equipment in the warehouse business, it was decided to use five criteria and to determine nine different alternatives in the selection of the load lifting platform selection used in the warehouses together with the purchasing department. Three criteria are beneficial and two are nonbeneficial criteria. The initial decision matrix, in which the criteria and alternatives of the problem are determined, is presented in Table 9.

MEREC, CRITIC and entropy methods were chosen among the objective weight determination methods in order to determine the criteria weights, perform the analyzes and compare. The computational findings of the third example were compared using different weight determination methods, and the results are presented in Table 10.

Pearson correlation analysis was performed, assuming that the findings were suitable for the normal distribution. CRITIC method findings were also found to have negative correlations that were not significant. It can be said that the entropy method assigns a high

Figure 3. The weights of the methods of Example 2

	C1-B-Capacity	C2-NB-price	C3-B-Platform size	C4-NB-platform weight	C5-B-Lift height
A1	2000	40,754	850*1300*360	295	2
A2	300	43,045	2250*1350*1530	1380	10
A3	350	35,915	910*500*53	142	1.3
A4	230	41,178	2260*810*1100	1850	8
A5	300	29,096	1850*1300*1200	750	4
A6	1000	26,583	1000*1600*990	186	1
A7	700	22,523	1220*610*445	195	1.5
A8	800	22,467	1220*610*60	172	1.5
A9	500	20,176	815*500*50	82	1

Note(s): B = beneficial criteria; NB = nonbeneficial criteria

Table 9. Initial decision matrix of Example 3

degree of importance to those with high criteria variances, that is, it emphasizes the high values of the alternatives on the basis of criteria. Furthermore, positive, very strong and significant correlations were obtained between MEREC, MEREC-H and MEREC-G with the entropy method. The standard deviation of the criteria weights obtained by the MEREC-G method was found to be relatively lower after the CRITIC method than the others. Findings obtained according to different methods can also be shown in Figure 4.

When the criteria weights found by the MEREC, MEREC-G, MEREC-H and entropy methods are examined graphically, it is observed that almost similar weights are obtained. However, entropy produces more discrete scores, while the MEREC-G method tends to produce scores that are closer to each other (closer to the mean) than others (except CRITIC). CRITIC method weights were similarly close to each other.

In fact, since the purpose of this study is to examine the use of the geometric/harmonic mean, which can obtain findings closer to the mean, considering that very different criteria weights cannot be found with the logarithmic measure applied in the MEREC method, it has been shown that especially the MEREC-G (with lower standard deviation and closer to the mean) and then the MEREC-H methods can be applied with the examples performed.

In addition, a different evaluation was made for this example separately from the others. Since the MEREC method is based on the removal effect of the criteria on the overall performance, we also performed a kind of sensitivity analysis of the change in the weights of the criteria by removing each alternative. We examined the change of criteria weights by removing each alternative separately. We present the criteria weights thus obtained for MEREC-G in Table 11.

Table 11 presents the initial weights and the criteria weights when each alternative is removed. For instance, when the A1 alternative is removed, the scores of all criteria are presented again in the A1 column. Alternative A2 has the lowest standard deviation (std.) and

	MEREC	MEREC-G	MEREC-H	CRITIC	Entropy	
w1	0.1201	0.0880	0.0377	0.1648	0.1344	
w2	0.0511	0.1278	0.0540	0.2139	0.0205	
w3	0.4329	0.3952	0.4676	0.1974	0.3648	
w4	0.2824	0.2664	0.3849	0.1941	0.2735	
w5	0.1135	0.1225	0.0557	0.2298	0.2068	Std. deviation
MEREC	1.0000					0.15578
MEREC-G	0.9640	1.0000				0.12872
MEREC-H	0.9590	0.9720	1.0000			0.20873
CRITIC	−0.1933	−0.0216	−0.1185	1.0000		0.02430
Entropy	0.9260	0.8396	0.8524	−0.0662	1.0000	0.13146

Table 10. Comparisons by different methods of Example 3

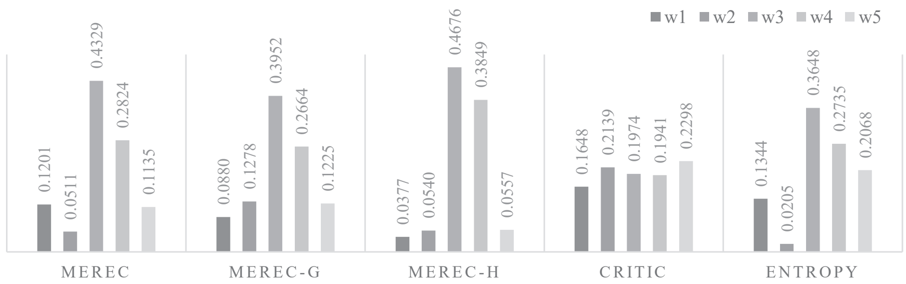

Figure 4. The weights of the methods of Example 3

coefficient of variation (CoV), while alternative A3 has the highest standard deviation and CoV. There are no major changes in the criteria weights in the overall evaluation. The change in criteria weights can be better examined graphically in Figure 5.

In Figure 5, where the change in criteria weights obtained by the MEREC-G method is monitored, when the A3 alternative is removed, there has been a relatively greater change in the w3-platform size and w4-platform weight criteria. It is caused by the fact that the A3 alternative takes one of the minimum values in the C3 and C4 criteria. When the A3 alternative was removed, w3 increased more and w4 decreased more.

Moreover, the change in criteria weights obtained by the MEREC-H method is presented in Table 12.

Table 12 shows the change in criteria weights as each alternative is removed. As in the MEREC-G method, there is no major change in criteria weights in general. Alternative A5 has the lowest standard deviation and CoV, while alternative A3 has the highest standard deviation and CoV. The standard deviations for MEREC-H are almost double that of MEREC-G. Increasing the standard deviations increases the variability. But in terms of variability, it should be noted that MEREC-G gives better findings than the MEREC method (MEREC CoV:77.90). The change in criteria weights for the MEREC-H method can be better examined graphically in Figure 6.

The removal of the A3 alternative had more impact. Otherwise, the removal of any alternative did not cause significant changes in the criteria w1, w2 and w5, which have very low criteria weights (there was a change of around 1% in these criteria). The effect of removing the alternatives caused 18.19% changes in the highest and lowest scores in the w3

	Origin	A1	A2	A3	A4	A5	A6	A7	A8	A9
w1	0.088	0.084	0.083	0.091	0.097	0.082	0.093	0.089	0.091	0.097
w2	0.128	0.118	0.133	0.129	0.117	0.128	0.126	0.125	0.127	0.141
w3	0.395	0.397	0.362	0.438	0.392	0.362	0.382	0.398	0.418	0.421
w4	0.266	0.282	0.292	0.217	0.273	0.292	0.284	0.272	0.249	0.225
w5	0.123	0.119	0.130	0.125	0.121	0.136	0.115	0.116	0.116	0.116
std.	0.129	0.135	0.120	0.141	0.128	0.120	0.127	0.132	0.136	0.133
mean	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
CoV	64.34	67.25	60.11	70.59	64.18	60.22	63.43	65.75	68.03	66.41

Table 11. Removal effect of alternatives with the MEREC-G method

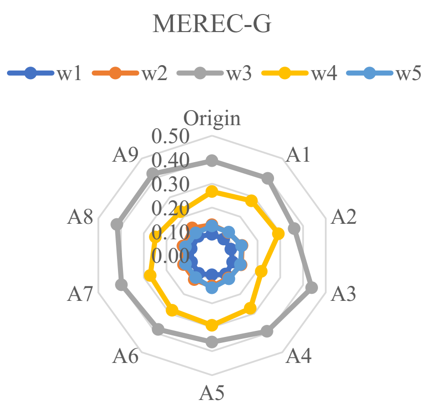

Figure 5. Change in weights with MEREC-G

Table 12. Removal effect of alternatives with the MEREC-H method

	Origin	A1	A2	A3	A4	A5	A6	A7	A8	A9
w1	0.038	0.038	0.040	0.033	0.044	0.041	0.038	0.034	0.039	0.040
w2	0.054	0.049	0.059	0.052	0.056	0.060	0.055	0.049	0.049	0.059
w3	0.468	0.460	0.417	0.575	0.451	0.393	0.439	0.464	0.506	0.538
w4	0.385	0.402	0.425	0.285	0.388	0.444	0.412	0.402	0.357	0.305
w5	0.056	0.051	0.060	0.055	0.061	0.062	0.056	0.051	0.049	0.058
std.	0.209	0.212	0.202	0.234	0.202	0.200	0.206	0.214	0.218	0.218
mean	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
CoV	104.37	106.01	100.97	116.76	100.81	100.03	103.17	106.97	108.83	109.22

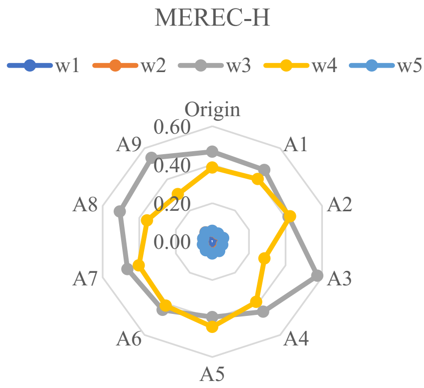

Figure 6. Change in weights with MEREC-H

criteria. In the w4 criteria, it is 15.86%. In the MEREC-G method, the highest change was around 7%, and again in the w3 and w4 criteria.

5. Practical and theoretical implications

Decision-making problems have been investigated in the scientific literature for many years. Various alternatives and criteria by which these alternatives are evaluated are needed for decision-making problems that occur in every moment of human life. The criteria can be given subjective weights according to the judgment of the decision-maker or objective weights according to the scores of the alternatives. In this study, research is presented within the framework of objective methods.

In many decisions made in daily real life, people evaluate alternatives according to various criteria. As a result of the fact that an item sold in retail is found to be too expensive, an important evaluation criterion for this item disappears, and other alternatives can be evaluated according to the missing criterion. If a product is not in stock in an e-purchase made over the Internet and if the indispensable feature of this product is excluded from the evaluation, other alternatives can be evaluated according to the remaining criteria. Similarly, in a decision problem where there are many criteria, for example, criteria with low importance (such as below 5%) may need to be removed and other criteria should be reevaluated. On the other hand, it can be ensured that the low-importance criteria have a low effect on the overall performance. In such cases, it is thought that the MEREC method can be more helpful to the decision-maker than other methods. Examined examples show that the MEREC-G method can be used to find more reasonable or average results than other weight determination methods such as entropy. For the stated reasons, it can be expected that the MEREC method and MEREC-G variant will be used more in real-time engineering and social applications, and various areas in future studies.

It should also be noted that when this study was designed, there were only 24 studies conducted using the MEREC method, and these studies have already been referenced in the literature section. However, during the evaluation phase of the manuscript (even though the MEREC method was not applied in all of the 134 available studies, but referenced), the MEREC method was accepted by a large number of researchers in a short time and its recognition increased (Scholar, 2023). Despite this, no study criticizes the nature of the MEREC method. How the calculation steps of the MEREC method were derived was not questioned, only accepted and applied in the studies. How can science exist without question? Criticizing/expanding/reviewing/looking from a point of different perspective enables a study that has just been brought to the literature to both reveal its weaknesses (if any) and to make it strong. With these assumptions, it is thought that this study contributes to the modification/strengthening of the MEREC method. In regards to its practical contribution, the study and its results can benefit researchers in terms of more reasonable, simple and rational calculation stages by using multiplicative functions instead of non-logarithmic measures. Although many calculations are made on electronic devices today, it should be said that simpler calculation is more convenient and accepted than more complicated ones.

6. Conclusion

As one of the objective weight determination methods, the nonlinear logarithmic measure is used in the MEREC method, which removes the effects of the criteria on the overall performance and is based on deviations. The nonlinear logarithmic measurement procedure present in the MEREC method calculation steps can be modified with simpler mathematical operations to make it easier and more understandable. The comparison of criteria weights can be done by the MEREC-G method using the geometric mean, and the MEREC-H method using the harmonic mean.

In this context, the determination of the criteria weights can be generalized: the criteria of the initial decision matrix/elements, normalization of the initial matrix, comparison of the alternatives and/or criteria and obtaining the criteria weights separately are performed. Among these stages, especially the third stage differs in various criteria weight determination methods. In this study, we focused on the comparison of alternatives and/or criteria that can be pronounced as the third stage. Instead of the nonlinear logarithmic measure used in the MEREC method, we thought to obtain results that are closer to the mean and have a lower standard deviation. We calculated the overall performance of the criteria by introducing the MEREC-G method, in which the geometric mean of the normalized observation scores, and the MEREC-H method, in which the harmonic mean of the normalized observation scores is taken. We followed the procedure based on deviations from the mean and the removal effect of criteria on overall performance.

To introduce and compare the MEREC-G and MEREC-H methods, we present the findings with the first example using five alternatives and four criteria, and the second example using 10 alternatives and seven criteria, previously used by Keshavarz-Ghorabaee *et al.* (2021, pp. 9–11). After then, we used another example with nine alternatives and five criteria. We found very strong and significant correlations between MEREC-G and MEREC-H methods and MEREC and entropy methods. In the MEREC method, the criteria's obtaining very high or very low weight scores do not depend on the high or low values of the criteria; on the contrary, it depends on whether there is too much difference between the lowest and highest values of the criteria. This situation can be observed by decreasing the criterion values of any criterion equally. For example, in the third example, all values in the C3 criteria were reduced by 1/1000 and the same criteria weights were obtained.

Moreover, we found the standard deviation of the MEREC-G method findings to be lower than the other methods, and we observed that the findings were relatively close to the mean. We have shown that the MEREC-G and MEREC-H methods can be applied to various problems, considering that they are more clear, simple and more understandable. It is recommended that MEREC, MEREC-G and MEREC-H methods can be used when it is desired to use an objective weight determination method by considering only the values of the alternatives, rather than determining the weights subjectively based on the limited/biased/emotional/complex information/judgments of the decision-makers when it is desired to determine the criteria weights.

Since it has been observed that the criteria weight determination methods differ from each other at various stages, it is thought that future studies can focus on the integration of these methods. Furthermore, it is recommended that the validity of the MEREC-G and MEREC-H methods presented in this study may be tested by applying them to other problems. It is considered that the comparison with the CRITIC method in three different examples applied in the study does not make much difference; instead, comparisons can be made with other objective methods, such as the simultaneous evaluation of criteria and alternatives (SECA) method, standard deviation, mean weight and considering other methods in future studies.

References

Ahmad, S., Ali, M., Khan, Z.A. and Asjad, M. (2022), "Investigating the effect of input variables on the performance of FMS followed by multi-response optimization: a simulation study", *Materials Today: Proceedings*, Vol. 64, pp. 1500-1503, doi: 10.1016/j.matpr.2022.05.169.

Bączkiewicz, A. and Wątróbski, J. (2022), "Crispyn-A Python library for determining criteria significance with objective weighting methods", *SoftwareX*, Vol. 19, 101166.

Chaurasiya, R. and Jain, D. (2022), "Hybrid MCDM method on pythagorean fuzzy set and its application", *Decision Making: Applications in Management and Engineering*, ONLINE FIRST section, pp. 1-20, doi: 10.31181/dmame0306102022c.

Diakoulaki, D., Mavrotas, G. and Papayannakis, L. (1995), "Determining objective weights in multiple criteria problems: the CRITIC method", *Computers and Operations Research*, Vol. 22 No. 7, pp. 763-770.

Ecer, F. and Pamucar, D. (2022), "A novel LOPCOW-DOBI multi-criteria sustainability performance assessment methodology: an application in developing country banking sector", *Omega*, Vol. 112, pp. 1-17, doi: 10.1016/j.omega.2022.102690.

Ghosh, S. and Bhattacharya, M. (2022), "Analyzing the impact of COVID-19 on the financial performance of the hospitality and tourism industries: an ensemble MCDM approach in the Indian context", *International Journal of Contemporary Hospitality Management*, Vol. 34 No. 8, pp. 1-30.

Goswami, S.S., Mohanty, S.K. and Behera, D.K. (2022), "Selection of a green renewable energy source in India with the help of MEREC integrated PIV MCDM tool", *Materials Today: Proceedings*, Vol. 52, pp. 1153-1160.

Hadi, A. and Abdullah, M.Z. (2022), "Web and IoT-based hospital location determination with criteria weight analysis", *Bulletin of Electrical Engineering and Informatics*, Vol. 11 No. 1, pp. 386-395.

Hezam, I.M., Mishra, A.R., Rani, P., Cavallaro, F., Saha, A., Ali, J., Strielkowski, W. and Štreimikienė, D. (2022), "A hybrid intuitionistic fuzzy-MEREC-RS-DNMA method for assessing the alternative fuel vehicles with sustainability perspectives", *Sustainability*, Vol. 14 No. 9, p. 5463.

Jovčić, S. and Průša, P. (2021), "A hybrid MCDM approach in third-party logistics (3PL) provider selection", *Mathematics*, Vol. 9 No. 21, p. 2729.

Kamali Saraji, M. and Streimikiene, D. (2023), "A novel extended fermatean fuzzy framework for evaluating the challenges to sustainable smart city development", *Real Life Applications of Multiple Criteria Decision Making Techniques in Fuzzy Domain*, Springer, Singapore, pp. 37-58.

Kaya, S.K., Ayçin, E. and Pamucar, D. (2022), "Evaluation of social factors within the circular economy concept for European countries", *Central European Journal of Operations Research*, Vol. 31, doi: 10.1007/s10100-022-00800-w.

Keleş, N. (2022a), "Okul yeri seçiminde kullanılan kriterlerin analitik hiyerarşi prosesi yöntemiyle önemlerinin belirlenmesi", *Artuklu Kaime Uluslararası İktisadi ve İdari Araştırmalar Dergisi*, Vol. Special Issue, pp. 135-154.

Keleş, N. (2022b), "Determining the weights of the criteria used in the selection of load lifting platforms with MEREC and Entropy methods", *International Production and Supply Chain Symposium*, Vol. 1 No. 1, pp. 55-56, E-ISBN 978-605-71203-3-5, Sinop/Turkey.

Keshavarz-Ghorabaee, M. (2021), "Assessment of distribution center locations using a multi-expert subjective–objective decision-making approach", *Scientific Reports*, Vol. 11 No. 1, pp. 1-19, doi: 10.1038/s41598-021-98698-y.

Keshavarz-Ghorabaee, M., Amiri, M., Zavadskas, E.K., Turskis, Z. and Antucheviciene, J. (2021), "Determination of objective weights using a new method based on the removal effects of criteria (MEREC)", *Symmetry*, Vol. 13 No. 4, p. 525.

Lee, P.T.W., Lin, C.W. and Shin, S.H. (2012), "A comparative study on financial positions of shipping companies in Taiwan and Korea using entropy and grey relation analysis", *Expert systems with Applications*, Vol. 39 No. 5, pp. 5649-5657.

Marinković, M., Zavadskas, E.K., Matić, B., Jovanović, S., Das, D.K. and Sremac, S. (2022), "Application of wasted and recycled materials for production of stabilized layers of road structures", *Buildings*, Vol. 12 No. 5, p. 552.

Mishra, A.R., Saha, A., Rani, P., Hezam, I.M., Shrivastava, R. and Smarandache, F. (2022a), "An integrated decision support framework using single-valued-MEREC-MULTIMOORA for low carbon tourism strategy assessment", *IEEE Access*, Vol. 10, pp. 24411-24432.

Mishra, A.R., Tripathi, D.K., Cavallaro, F., Rani, P., Nigam, S.K. and Mardani, A. (2022b), "Assessment of battery energy storage systems using the intuitionistic fuzzy removal effects of criteria and the measurement of alternatives and ranking based on compromise solution method", *Energies*, Vol. 15 No. 20, p. 7782.

Narayanamoorthy, S., Parthasarathy, T.N., Pragathi, S., Shanmugam, P., Baleanu, D., Ahmadian, A. and Kang, D. (2022), "The novel augmented Fermatean MCDM perspectives for identifying the optimal renewable energy power plant location", *Sustainable Energy Technologies and Assessments*, Vol. 53, 102488.

Nguyen, H.Q., Nguyen, V.T., Phan, D.P., Tran, Q.H. and Vu, N.P. (2022), "Multi-criteria decision making in the PMEDM process by using MARCOS, TOPSIS, and MAIRCA methods", *Applied Sciences*, Vol. 12 No. 8, p. 3720.

Nicolalde, J.F., Cabrera, M., Martínez-Gómez, J., Salazar, R.B. and Reyes, E. (2022), "Selection of a phase change material for energy storage by multi-criteria decision method regarding the thermal comfort in a vehicle", *Journal of Energy Storage*, Vol. 51, 104437.

Panchagnula, K.K., Sharma, J.P., Kalita, K. and Chakraborty, S. (2023), "CoCoSo method-based optimization of cryogenic drilling on multi-walled carbon nanotubes reinforced composites", *International Journal on Interactive Design and Manufacturing (IJIDeM)*, Vol. 17, pp. 279-297, doi: 10.1007/s12008-022-00894-1.

Pekkaya, M. and Keleş, N. (2022), "Determining criteria interaction and criteria priorities in freight village location selection process: the experts' perspective in Turkey", *Asia Pacific Journal of Marketing and Logistics*, Vol. 34 No. 7, pp. 1348-1367, doi: 10.1108/APJML-05-2021-0338.

Petrović, G., Pavlović, J., Madić, M. and Marinković, D. (2022), "Optimal synthesis of loader drive mechanisms: a group robust decision-making rule generation approach", *Machines*, Vol. 10 No. 5, p. 329.

Popović, G., Karabašević, D. and Stanujkić, D. (2021), "Multiple-criteria framework for cloud service selection", *PaKSoM 2021, Proceedings of the 3rd Virtual International Conference Path to a Knowledge Society- Managing Risks and Innovation*, pp. 377-382.

Rani, P., Mishra, A.R., Saha, A., Hezam, I.M. and Pamucar, D. (2022), "Fermatean fuzzy heronian mean operators and MEREC-based additive ratio assessment method: an application to food waste treatment technology selection", *International Journal of Intelligent Systems*, Vol. 37 No. 3, pp. 2612-2647.

Saha, M., Panda, S.K., Panigrahi, S. and Taniar, D. (2022), "An efficient composite cloud service model using multi-criteria decision-making techniques", *The Journal of Supercomputing*. doi: 10.1007/s11227-022-05013-1.

Sapkota, G., Das, S., Sharma, A. and Ghadai, R.K. (2022), "Comparison of various multi-criteria decision methods for the selection of quality hole produced by ultrasonic machining process", *Materials Today: Proceedings*, Vol. 58 No. 2, pp. 702-708, doi: 10.1016/j.matpr.2022.02.221.

Scholar (2023), available at: https://scholar.google.com/scholar?cites=10177963591141253468as_sdt=2005&sciodt=0,5&hl=tr (accessed 10 January 2023).

Shanmugasundar, G., Sapkota, G., Čep, R. and Kalita, K. (2022), "Application of MEREC in multi-criteria selection of optimal spray-painting robot", *Processes*, Vol. 10 No. 6, p. 1172.

Shemshadi, A., Shirazi, H., Toreihi, M. and Tarokh, M.J. (2011), "A fuzzy VIKOR method for supplier selection based on entropy measure for objective weighting", *Expert systems with Applications*, Vol. 38 No. 10, pp. 12160-12167.

Simić, V., Ivanović, I., Đorić, V. and Torkayesh, A.E. (2022a), "Adapting urban transport planning to the COVID-19 pandemic: an integrated fermatean fuzzy model", *Sustainable Cities and Society*, Vol. 79, pp. 1-26, 103669.

Simić, V., Gokasar, I., Deveci, M. and Švadlenka, L. (2022b), "Mitigating climate change effects of urban transportation using a type-2 neutrosophic MEREC-MARCOS model", *IEEE Transactions on Engineering Management*, pp. 1-17, doi: 10.1109/TEM.2022.3207375.

Toslak, M., Aktürk, B. and Ulutaş, A. (2022), "MEREC ve WEDBA yöntemleri ile bir lojistik firmasının yıllara göre performansının değerlendirilmesi", *Avrupa Bilim ve Teknoloji Dergisi*, No. 33, pp. 363-372.

Trung, D.D. and Thinh, H.X. (2021), "A multi-criteria decision-making in turning process using the MAIRCA, EAMR, MARCOS and TOPSIS methods: a comparative study", *Advances in Production Engineering and Management*, Vol. 16 No. 4, pp. 443-456.

Ulutaş, A. and Cengiz, E. (2018), "CRITIC ve EVAMIX yöntemleri ile bir işletme için dizüstü bilgisayar seçimi", *Journal of International Social Research*, Vol. 11 No. 55, pp. 881-887, doi: 10.17719/jisr.20185537260.

Ulutaş, A., Stanujkic, D., Karabasevic, D., Popovic, G. and Novaković, S. (2022), "Pallet truck selection with MEREC and WISP-S methods", *Strategic Management*, Vol. 27 No. 4, doi: 10.5937/StraMan2200013U.

Wang, T.C. and Lee, H.D. (2009), "Developing a fuzzy TOPSIS approach based on subjective weights and objective weights", *Expert systems with Applications*, Vol. 36 No. 5, pp. 8980-8985.

Yu, Y., Wu, S., Yu, J., Chen, H., Zeng, Q., Xu, Y. and Ding, H. (2022), "An integrated MCDM framework based on interval 2-tuple linguistic: a case of offshore wind farm site selection in China", *Process Safety and Environmental Protection*, Vol. 164, pp. 613-628.

Zhai, T., Wang, D., Zhang, Q., Saeidi, P. and Raj Mishra, A. (2022), "Assessment of the agriculture supply chain risks for investments of agricultural small and medium-sized enterprises (SMEs) using the decision support model", *Economic Research-Ekonomska Istraživanja*, pp. 1-33, doi: 10.1080/1331677X.2022.2126991.

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