Pamukkale Univ Muh Bilim Derg, 29(1), 30-44, 2023

Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi

Pamukkale University Journal of Engineering Sciences

Group decision making in best-worst method when the best and worst are not unique: case study of scholar selection

En iyi ve en kötünün tek olmadığı durumlarda en iyi-en kötü yöntemi ile grup kararı verme: bursiyer seçimine ilişkin vaka çalışması

Esra AYTAÇ ADALI[1*], *Atalay ÇAĞLAR*[2]

[1]Department of Business Administration, Faculty of Economics and Administrative Sciences, Pamukkale University, Denizli, Turkey.
eaytac@pau.edu.tr

[2]Department of Econometrics, Faculty of Economics and Administrative Sciences, Pamukkale University, Denizli, Turkey.
acaglar@pau.edu.tr

Received/Geliş Tarihi: 17.11.2021 Revision/Düzeltme Tarihi: 17.02.2022 doi: 10.5505/pajes.2022.08043
Accepted/Kabul Tarihi: 14.03.2022 Research Article/Araştırma Makalesi

Abstract

Scholarships for the students are the financial supports provided by the government or institutions. There may be a great number of competing applicants with the knowledge, skills and abilities to successfully fulfill the scholarship needs. So, it is difficult to select the most suitable students among multiple applicants for these providers. In this study, scholarship students' selection is handled as a complex decision making problem, and this problem is solved by integration of two Multi Criteria Decision Making (MCDM) methods, Best-Worst Method (BWM) and COmbined COmpromise SOlution (CoCoSo). In order to demonstrate the applicability of these methods to the scholarship student selection problem, a real problem is solved. This problem is designed as a group decision making problem, and BWM, the improved Analytic Hierarchy Process method, is employed to derive the criteria weights. A solution to the problem where decision makers' best and worst criteria are not common and unique is suggested. On the other hand, CoCoSo method is used for the ranking purposes of the applicants. The novelty of this study is that scholarship selection problem is solved with BWM and CoCoSo methods for the first time. The integrated usage of BWM and CoCoSo methods is thought as suitable and effective methods to rank or select the best candidate or alternative among a number of candidates or alternatives because of satisfactory results.

Keywords: Scholarship student selection, MCDM, BWM, CoCoSo.

Öz

Öğrencilere yönelik burslar, devlet veya kurumlar tarafından sağlanan mali desteklerdir. Sağlanan bursun gerekliliklerini başarıyla yerine getirmek için gerekli olan bilgi, beceri ve yeteneklere sahip çok sayıda rakip öğrenci olabilir. Bu nedenle, burs sağlayıcılar için birden fazla başvuru arasından en uygun öğrencileri seçmek zordur. Bu çalışmada, burs seçimi karmaşık bir karar verme problemi olarak ele alınmış ve bu problem, Çok Kriterli Karar Verme (ÇKKV) yöntemlerinden olan En İyi-En Kötü Yöntemi (BWM) ve Birleşik Uzlaşma Çözümü (CoCoSo yöntemi) birlikte kullanılarak çözülmüştür. Bu yöntemlerin burslu öğrenci seçme problemine uygulanabilirliği, gerçek bir problemin çözümü ile gösterilmiştir. Problem, grup karar verme problemi olarak tasarlanmıştır. Problemde kriterlerin ağırlıkları, Analitik Hiyerarşi Süreci yönteminin geliştirilmiş bir hali olan BWM ile hesaplanmıştır. Aynı zamanda, karar vericilerin en iyi ve en kötü kriterlerinin ortak ve tek olmadığı probleme bir çözüm önerilmiştir. Öte yandan, başvuran adayların sıralamaları için CoCoSo yöntemi kullanılmıştır. Bu çalışma ile bursiyer seçim problem, ilk kez BWM ve CoCoSo yöntemleri ile çözülmüştür. Çalışmadan elde edilen tatmin edici sonuçlar, bir dizi aday veya alternatif arasından en iyi adayı veya alternatifi sıralamak ya da seçmek için BWM ve CoCoSo yöntemlerinin birlikte kullanımının uygun ve etkili bir yaklaşım olacağını göstermektedir.

Anahtar kelimeler: Bursiyer öğrenci seçimi, ÇKKV, BWM, CoCoSo.

1 Introduction

Scholarship for a student is a type of financial aid, and it is in the form of a grant that does not have to be repaid by the student. Scholarships may be in different shapes and sizes. They are offered to students by government, university, a private company or an organization for financial need or achievement in academics [1],[2]. Although there are many reasons that a student has to apply the scholarship, the main reason is that scholarship helps to reduce the cost burden of the education life of the students [3]. Sometimes the number of applicants who have the necessary skills and knowledge to successfully fulfill the needs of the scholarship may exceed the number of the scholars designed by a scholarship provider. Under this circumstance, selecting eligible students from competing applicants requires a detailed analysis to determine the eligibility of applicants [2]. The selection process involves tasks of interviewing with the applicants, evaluating their applications, and making final decision. These tasks are to be completed by a selection committee. During the selection process, many multiple criteria have to be taken into consideration simultaneously to specify the students who deserve scholarship [4].

In the literature, the scholarship student selection has been assumed as Multi Criteria Decision Making (MCDM) problem, and there are few studies about it. Yeh [5],[6] formed this selection as Multi Attribute Decision Making (MADM) problem, and presented a solution based on total sum, Simple Additive Weighting (SAW), Weighted Product (WP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods. Uyun and Riadi [7] proposed to apply fuzzy MADM including TOPSIS and WP for scholarship student selection at Universitas Islam Negeri Sunan Kalijaga. Similarly, Wimatsari et al. [8] demonstrated the scholarship selection with a case by using fuzzy MADM including TOPSIS method. Saptarini et al. [9] used Analytic Hierarchy Process (AHP) for finding scholarship criteria weights and TOPSIS method for ranking the students

*Corresponding author/Yazışılan Yazar

who apply the scholarship. Purba and Sembiring [10] proposed a decision support system that uses Preference Ranking Organization Methods for Enrichment Evaluations (PROMETHEE) method for the scholarship recipients selection at Polytechnic Unggul LP3M. Mesran et al. [11] performed Preference Selection Index (PSI) method for scholarship student selection process. They argued that PSI method facilitates the selection process in terms of not assigning criteria weights. Marfuah and Widiantoro [4] used AHP method for scholarship selection process at Universal University. Similarly, Puspitasari et al. [12] developed a decision support system based on AHP for scholarship determination. Rizana and Soesanto [13] integrated AHP and factor rating to find the selection criteria weights, and rank the scholarship applicants. Mahmud et al. [14] determined the criteria and sub-criteria for student selection, and applied fuzzy AHP method to select the students. Anamisa et al. [15] proposed to use SAW and TOPSIS methods for scholarship grantee selection. Mufizar et al. [16] combined Multifactor Evaluation Process (MFEP) and Distance to the Ideal Alternative (DIA) to specify the majors and the scholarship recipient. Utami and Ruskan [17] developed a decision support system applying Multi-Objective Optimization method on the basis of Ratio Analysis (MOORA) to determine the eligible students among the participants for Yayasan Alumni scholarship. MOORA method was also used as a selection method by Mardhiyyah et al. [2] for the scholarship selection process. Oktaviani et al. [18] established a decision support system that uses WP and SAW methods for the scholarship recipient selection process. Rafida et al. [19] proposed to apply Simple Multi-Attribute Rating Technique (SMART) method for scholarship selection, and demonstrated a case study in STMIK Widya Cipta Dharma.

In this study, it is aimed to solve scholarship student selection problem with two MCDM methods, Best-Worst Method (BWM) and COmbined COmpromise SOlution (CoCoSo). BWM is performed for weighting the scholarship student selection criteria while CoCoSo is performed for ranking of the applicants. The educational foundation that provides the scholarship wants to determine the scholarship criteria and the criteria weights together with the selection committee. From this point of view, the use of BWM is appropriate for the subjective determination of criteria weights. BWM was developed by Rezaei [20], and it is an improved version of AHP that was developed by Saaty [21]. Although AHP is widely preferred for solving MCDM problems, there are some disadvantages. The main disadvantage of AHP is the number of pairwise comparisons that are based on the number of the levels in the hierarchy. Namely, the hierarchy expansion requires more pairwise comparisons, computation, more time and effort [22],[23]. BWM overcomes this disadvantage of AHP in terms of determining the best and the worst criteria, and forming pairwise comparison between each of two criteria (best and worst) and the other criteria [20]. On the other hand, CoCoSo was proposed by Yazdani et al. [24]. It is the integration of two well-known MCDM methods, SAW and Exponentially Weighted Product (EWP). It uses different aggregation procedure for ranking the alternatives [25]. With this feature, the CoCoSo method offers a solution that uses different methods as well as different ways of aggregation. This solution also includes the advantages of all the methods that CoCoSo method contains. In this sense, as Yazdani [24] stated, the CoCoSo method provides a compromise solution, and the compromise solution is very important in that it is a solution that meets all the requirements simultaneously for problems that contain generally unmeasurable and conflicting criteria. Considering all these situations, it is appropriate to use the CoCoSo method in scholarship selection. Also, application results show that the usage of two methods is suitable and efficient for the application of scholarship selection in terms of being simple, and requiring fewer and understandable formulations.

In the line with the brief explanations mentioned above regarding scope of the study, the contributions of the study can be stated as follows:

- The scholarship selection problem is designed as a group decision-making problem,
- BWM is performed to determine the scholarship selection criteria weights,
- The main characteristic of the handled problem is that the best and worst criteria are not unique for each selection committee member. BWM method is applied to address this situation,
- Selection of the best scholar among scholars who fulfil all criteria is performed by CoCoSo method. With this selection, it is thought that an easy-to-understand and practical methodology has been developed for the decision makers on this subject,
- To the best of our knowledge, the integration of BWM and CoCoSo methods in scholarship selection is new in MCDM literature.

The rest of this study is organized as follows. The proposed methodology, the methodological backgrounds of BWM and CoCoSo methods are provided in Section 2. The application of the scholarship selection based on BWM and CoCoSo methods is demonstrated with a real case in Section 3. Then, application results are given and discussed. Lastly, recommendations for further studies are presented.

2 Proposed methodology

An integrated method based on BWM and CoCoSo methods is proposed in this study. In the first phase of the proposed method, criteria weights are determined by BWM. It is conducted in a group decision making environment. Also, the best and worst criteria of the decision makers are not common, and they are more than one. In the second phase of the proposed method, the decision alternatives are listed with CoCoSo. The criteria weights obtained from the BWM in the first phase are transferred to the second phase. The flowchart for the proposed methodology in this study is shown in Figure 1. In this sense, first of all, BWM and CoCoSo methods are explained in detail. Also, the integrated method proposed in this study is explained below.

2.1 BWM when the best and worst are not unique

BWM is one of the MCDM methods. It was firstly proposed by Rezaei [20]. It is a comparison-oriented method, and assumed as an enhancement of AHP method [26],[27]. Namely, it can be used to derive the subjective criteria weights. For this, first of all, the best and worst criteria are determined by the decision maker. Then, pairwise comparisons are formed between each of these two criteria and the other criteria. A maxi-min mathematical model based on these comparisons is solved, and the reliability of the comparisons is checked by a consistency ratio [26].

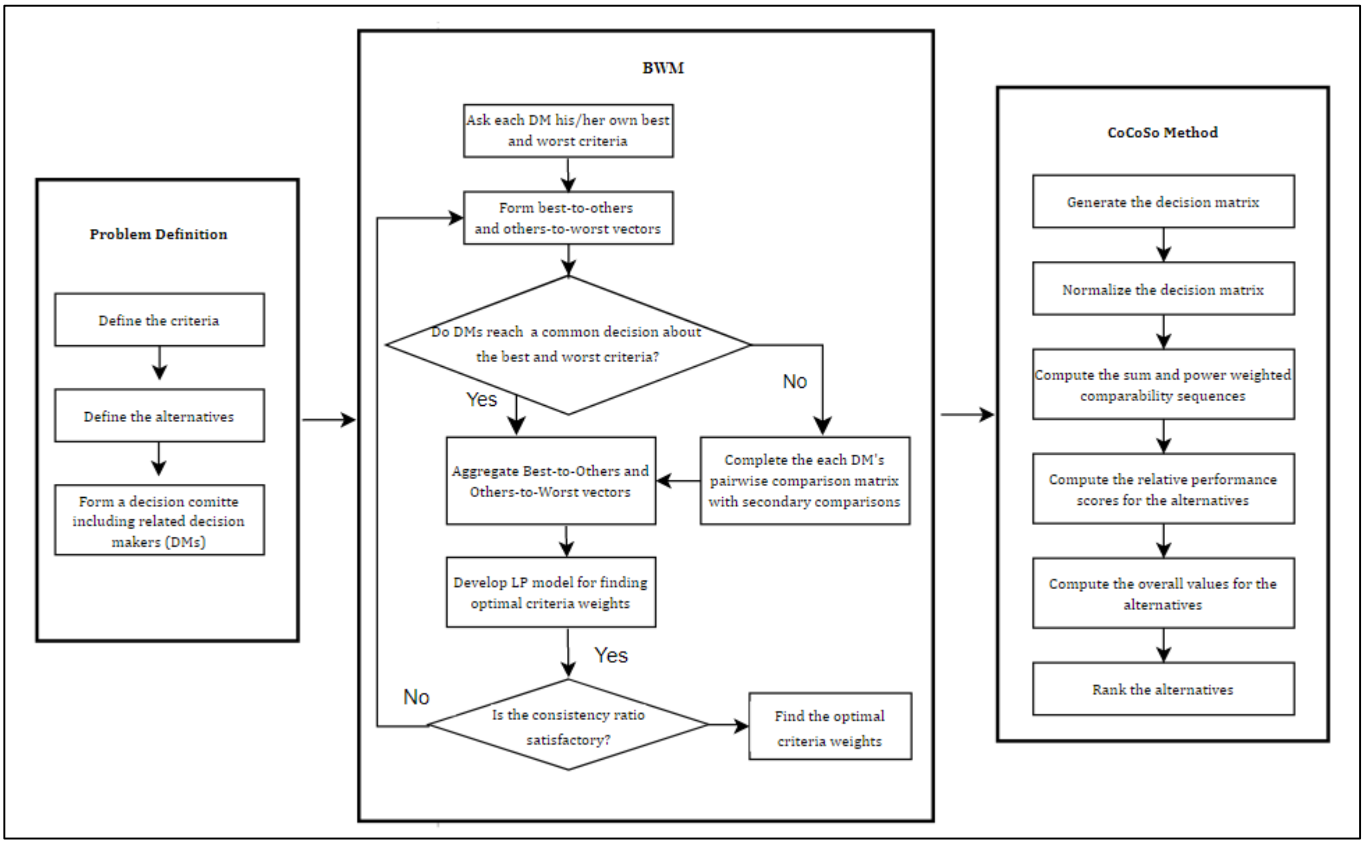

Figure 1. The flowchart for the proposed methodology.

In contrast to AHP, BWM requires fewer data, and provides more consistent results [28]. There are many studies that have applied BWM or combined it with other methods and theories in the literature. Some studies from the BWM literature are provided in Table 1.

In this section, the steps of BWM method, in which the best and worst criteria are not unique, are explained. In addition, the situation where the decision makers cannot reach a common decision on the best and worst criteria is also taken into account. The application steps are described as follows [20],[29],[30]:

Step 1. First of all, criteria of the problem (C_j ; j = 1,2, ...,n) are defined.

Step 2. It is assumed that the decision will be made by more than one decision maker. So, this part is designed as the group decision making. Considering the criteria defined in Step 1, each decision maker identifies his/her best (C_B) and worst (C_W) criteria from his/her own perspective. The most desired or important criterion is accepted as the best criterion, while the least desired or important criterion is considered as the worst criterion.

Step 3. Each decision maker determines the pairwise comparisons of the best criterion over all other criteria by using Saaty's 1 to 9 scale shown in Table 2. Best-to-Others vector for the *k*th decision maker (k=1,2,...,K) is expressed as:

$$A_B^k = \{a_{B1}^k, a_{B2}^k, \dots, a_{Bn}^k\} \tag{1}$$

a_{Bj}^k is the preference of the best criterion over *j*th criterion for *k*th decision maker, and $a_{BB} = 1$.

Step 4. Each decision maker determines the pairwise comparisons of all criteria over the worst criterion by using Saaty's 1 to 9 scale shown in Table 2. Others-to-Worst vector for the *k*th decision maker (k=1,2,...,K) is expressed as:

$$A_W^k = \{a_{1W}^k, a_{2W}^k, \dots, a_{nW}^k\}^T \tag{2}$$

a_{jW}^k is the preference of the *j*th criterion over the worst criterion for *k*th decision maker, and $a_{WW} = 1$.

Step 5. The aggregated Best-to-Others and Others-to-Worst vectors are computed. In this step, one of the following two situations occurs:

a) If the decision makers at the decision committee reach a common decision about the best and the worst criteria, then aggregated Best-to-Others and Others-to-Worst vectors are computed by performing various aggregation ways such as arithmetic mean, geometric mean, etc. Aggregated pairwise comparison matrix is developed as:

$$A = (a_{ij})_{n\times n} \tag{3}$$

$$a_{ij} = \left(\prod_{k=1}^{K} a_{ij}^k\right)^{1/K} \tag{4}$$

Table 1. Some studies from the BWM literature.

Method (s)	*Author (s)*	*Application Domain*
BWM	Bakker [33]	Strategy selection for trolley supply chain
	Rezaei [20]	Mobile phone selection
	Rezaei et al. [29]	Supplier segmentation and development
	Sadaghiani et al. [34]	External forces evaluation for oil and gas industry
	Rezaei et al. [31]	Supplier selection
	Rezaei et al. [35]	Determination of optimal freight bundling configuration for transport
	Gupta and Barua [36]	Evaluation of enablers for technological innovation
	Ren et al. [32]	Sustainability assessment of the technologies for the treatment of urban sewage sludge
	Bezerianos [28]	Country selection for oil and gas industry
	Ghaffari et al. [27]	Evaluation of key success factors for remotely-piloted helicopters industry
	Abadi et al. [37]	Strategy evaluation for medical tourism development
	Ecer [38]	Sustainability assessment of onshore wind plants
	Ulutaş [39]	Evaluation of vehicle selection criteria
	Bilgiç et al. [40]	Evaluation of renewable energy sources
	Arsu and Uğuz Arsu [41]	Personnel selection
	Öz [42]	Launch site location selection
BWM and TOPSIS	Akyüz et al. [43]	Non-Life Insurance Companies' performances evaluation
BWM and ELECTRE III	You et al. [44]	Site selection for cultural centers
Intuitionistic Fuzzy (IF) multiplicative preference relations and IF multiplicative BWM	Mou et al. [26]	Severity evaluation of pulmonary emphysema
BWM and VIKOR	Serrai et al. [45]	Evaluation of skyline web services
	Abdulkareem et al. [46]	Intelligent algorithms selection for image dehazing
BWM and SWOT analysis	Chitsaz and Azarnivand [47]	Evaluation of water shortage alleviation strategies
Fuzzy BWM	Guo and Zhao [48]	Three case studies including transportation mode selection, car selection and supplier performance evaluation
	Ketabchi and Ghaeli [49]	Risk assessment in oil projects
	Xu et al. [50]	Allocation of water rights
Z-BWM	Aboutorab et al. [51]	Supplier development
Fuzzy BWM and COPRAS	Amoozad Mahdiraji et al. [52]	Evaluation of key factors of sustainable architecture
BWM, VIKOR and GRA	Parhizgarsharif et al. [53]	Facility location selection
BWM and WASPAS	Kolagar [54]	Evaluation of cities for urban agriculture
	Arslanhan and Tosun [55]	Selection of transportation mode
BWM and ARAS	Bahrami et al. [56]	Determination of Cu potential zones
	Çakır and Can [57]	Evaluation of outsourcing companies for an accommodation company
	Çalık [58]	Target market selection
Fuzzy BWM and DEA	Kolagar et al. [59]	Evaluation of renewable energy sources
Interval type-2 fuzzy BWM and VIKOR	Wu et al. [60]	Green supplier selection
Interval-valued Pythagorean hesitant fuzzy BWM	Liu et al. [61]	Selection of 3PRLs on self-service mobile recycling machine
BWM and EDAS	Behzad et al. [62]	Solid waste management performance evaluation of Nordic countries
BWM and MABAC	Muravev and Mijic [63]	Provider selection
	Telli and Ayçin [64]	Teacher selection for a private school
BWM, MAIRCA, and MABAC	Özdağoğlu et al. [65]	Evaluation of performances of airport companies that use Isparta - Süleyman Demirel Airport
BWM, MABAC and PROMETHEE II	Nabeeh et al. [66]	Evaluation of hospital services
Bayesian BWM	Mohammadi and Rezaei [67]	Mobile phone selection
Fuzzy BWM and Z-WASPAS	Akbari et al. [68]	HSE risk prioritization
BWM and PROMETHEE	Ishizaka and Resce [69]	Evaluation of school performances for the OECD's PISA project
BWM and fuzzy TODIM	Karakış [70]	Supplier selection
Fuzzy Bayesian BWM	Yucesan et al. [71]	Evaluation of failure modes for a manufacturing facility

Table 2. Saaty's 1-9 scale [21].

Intensity of Importance	*Definition*
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values

b) If they do not have any common decision about the best and the worst criteria, aggregated Best-to-Others and Others-to-Worst vectors are not directly computed. Each decision maker's pairwise comparison matrix is completed by secondary comparisons to obtain an aggregated pairwise comparison matrix. Comparison a_{ij} is called as the secondary comparison if i nor j are the best or the worst criteria, and a_{ij} >1. As a result of these computations, pairwise comparison matrices of size nxn are obtained as much as the number of decision makers. k pairwise comparison matrices are aggregated with different aggregation methods as mentioned before. Thus, an aggregated nxn-sized pairwise comparison matrix reflecting the preferences of all decision makers is obtained.

From here, the aggregated Best-to-Others and Others-to-Worst vectors can be calculated using the aggregated pairwise comparison matrix. For this, first of all, row sums of the aggregated pairwise comparison matrix are calculated. The criterion with the highest row total is considered as the best criterion, while the criterion with the lowest row total is considered as the worst criterion. Concordantly, in the following steps of the method, the row with the best criterion is used as the Best-to-Others vector, and the row with the worst criterion is used as Others-to-Worst vector.

Step 6. Rezai et al. [31] developed a new Linear Programming (LP) model for finding optimal criteria weights namely, they proposed to use Linear Chebyshev BWM. In this study, the model for Linear Chebyshev BWM is performed for finding the optimal criteria weights. Maximum absolute differences $|w_B - a_{Bj}w_j|$ and $|w_j - a_{jW}w_W|$ for all j are minimized, and this model is shown in Eq. (5):

$$\begin{gathered}\min \max_j \{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W|\} \\ \text{s.t.} \quad \textstyle\sum_j w_j = 1 \\ w_j \geq 0 \quad \text{for all } j\end{gathered} \tag{5}$$

Model shown in Eq. (5) is transferred to the following LP model:

$$\begin{gathered}\min \xi^L \\ \text{s.t.} \quad |w_B - a_{Bj}w_j| \leq \xi^L \quad \text{for all } j \\ |w_j - a_{jW}w_W| \leq \xi^L \quad \text{for all } j \\ \sum_j w_j = 1 \\ w_j \geq 0 \ \text{ for all } j\end{gathered} \tag{6}$$

The model shown in Eq. (6) has only one solution. After solving Eq. (6), the optimal criteria weights $(w_1^*, w_2^*, \ldots, w_n^*)$ and ξ^{*L} (optimal value of ξ^L) are found [31].

Step 7. Consistency level of comparison is calculated in this step. A comparison is fully consistent when $a_{Bj} \times a_{jW} = a_{BW}$ (j=1,2,...,n). The consistency ratio of Linear Chebyshev BWM is calculated by Eq. (7):

$$\text{Consistency Ratio} = \frac{\xi^{*L}}{\text{Consistency Index}} \tag{7}$$

Consistency index depends on the value of a_{BW}. The value of a_{BW} may not be integer due to aggregation process in Step 5. In this case, the value of a_{BW} can be rounded up. The corresponding consistency index is presented in Table 3. The consistency ratio takes its value from the interval [0,1]. If the value of consistency ratio is close to zero, it means that comparison is consistent [32].

Table 3. Consistency index [20].

a_{BW}	1	2	3	4	5	6	7	8	9
Consistency index	0.00	0.44	1	1.63	2.30	3.00	3.73	4.47	5.23

2.2 CoCoSo method

CoCoSo method is one of the MCDM methods, and was developed by Yazdani et al. [24]. CoCoSo consists of two commonly used methods, SAW and EWP [72]. From this point of view, the ranking results of alternatives obtained from the method can be considered as a summary or presentation of compromise solutions [25]. Also, compromise solutions are computed by using different aggregation strategies in CoCoSo [73]. Since the day CoCoSo was proposed, it has many successful applications in the literature. Some of these studies are presented in Table 4. CoCoSo method requires the following steps [24],[72],[74]:

Step 1. The initial step is the generation of decision matrix (X).

$$X = [x_{ij}]_{mxn} = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \\ \mathrm{i} = 1,2 \ldots, \mathrm{m}\,; \mathrm{j} = 1,2, \ldots, \mathrm{n} \tag{8}$$

where x_{ij} is the performance value of ith alternative with respect to jth criterion.

Step 2: The decision matrix is normalized by performing the linear normalization procedure. Eq. (9a) and Eq. (9b) are used for the beneficial and non-beneficial criteria, respectively:

$$r_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \tag{9a}$$

$$r_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} \tag{9b}$$

where r_{ij} is the normalized value of x_{ij}.

Step 3. The weighted comparability sequences, the sum and power (S_i and P_i), for each alternative are computed.

$$S_i = \sum_{j=1}^{n} (w_j r_{ij}) \\ P_i = \sum_{j=1}^{n} (r_{ij})^{w_j} \tag{10}$$

where w_j is the weight of jth criterion. In this study, the criteria weights used in Eq.(10) are obtained from BWM given in Section 2.1.

Step 4. Relative performance scores of the alternatives are specified with three ways as shown in Eq.(11)-(13).

Table 4. Some studies about CoCoSo method from the literature.

Method (s)	Author(s)	Application domain
CoCoSo	Yazdani et al. [24]	Logistics provider selection
	Özdağoğlu et al. [78]	Ranking universities in Turkey
	Khan and Haleem [79]	Evaluation of circular practices
BWM and CoCoSo	Zolfani et al. [72]	Supplier selection
Full Consistency Method (FUCOM), and Interval Rough CoCoSo	Erceg et al. [80]	Stock management in the storage system
Taguchi and CoCoSo	Barua et al. [81]	Composite behavior evaluation
Hesitant Fuzzy Linguistic CoCoSo	Wen et al. [82]	Recruitment process of enterprises
Fuzzy BWM and Fuzzy CoCoSo	Ecer and Pamucar [83]	Supplier selection
CRITIC and CoCoSo	Akgül [84]	Evaluation of performances of 9 deposit banks
CRITIC and Pythagorean Fuzzy CoCoSo	Peng et al. [85]	Evaluation of 5G enterprises
CRITIC and Fuzzy CoCoSo	Peng and Huang [25]	Evaluation of financial risks
CRITIC and Neutrosophic Soft CoCoSo	Peng and Smarandache [86]	Evaluation of China's rare earth industry security
Fuzzy SWARA and CoCoSo	Ulutaş et al. [87]	Location selection for logistics center
Shannon Entropy and CoCoSo	Stanujkic et al. [88]	Ranking the countries with respect to indicators adopted from Agenda 2030
	Topal [89]	Evaluation of the financial performances of 10 electricity generation companies
Maximum Variance and CoCoSo	Lai et al. [90]	Cloud service provider selection
Correlation Coefficient and Standart Deviation (CCSD), and CoCoSo	Pala [91]	Evaluation of the financial performances of 9 construction businesses
Pythagorean Fuzzy CoCoSo	Liao et al. [92]	Green cold chain logistics distribution center selection
Integrated Determination of Objective Criteria Weights (IDOCRIW) and CoCoSo	Luo et al. [93]	Evaluation of tourism attractions
Fuzzy AHP and CoCoSo	Vikas and Mishra [94]	Critical success enablers of industry 4.0
Level Based Weight Assessment (LBWA) and CoCoSo	Gençkaya et al. [95]	Evaluation of 30 the official websites of 30 metropolitan municipalities
BWM, LBWA, and CoCoSo	Torkayesh et al. [74]	Healthcare performances' evaluations of several countries
CRITIC and Interval-Valued Fuzzy Soft CoCoSo	Peng et al. [96]	Intelligent health management
IVIF CoCoSo	Alrasheedi et al. [73]	Ranking of green growth indicators

$$k_{ia} = \frac{P_i + S_i}{\sum_{i=1}^{m}(P_i + S_i)} \quad (11)$$

$$k_{ib} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i} \quad (12)$$

$$k_{ic} = \frac{\lambda(S_i) + (1-\lambda)P_i}{\left(\lambda \max_i S_i + (1-\lambda)\max_i P_i\right)}, 0 \le \lambda \le 1 \quad (13)$$

Eq.(11) is the mean of scores obtained from WSM (Weighted Sum Method) and WPM (Weighted Product Method). Eq.(12) is the sum of relative scores obtained from WSM and WPM compared to the best alternative. Finally, Eq.(13) is the comprise solution for WSM and WPM. The threshold value (λ) is based on decision maker. It affects the flexibility and stability of the method [75]. There are different methods in the literature regarding the determination of λ value. For instance, Zavadskas et al. [76] proposed a formula based on the estimates of variances of relative importances of alternatives. Aytekin and Gündoğdu [77] obtained different alternative rankings with different λ values, and aggreated the rankings with the Copeland method. In the current study, λ value is set to 0.5 as in many studies in the literature. However, in the application section, the effect of change of this value on the rankings is investigated.

Step 5. The overall value of alternative (k_i) is determined by using Eq. (14):

$$k_i = (k_{ia}k_{ib}k_{ic})^{\frac{1}{3}} + \frac{1}{3}(k_{ia}+k_{ib}+k_{ic}) \quad (14)$$

Alternatives are ranked in ascending order. The alternative with the highest value of k_i is ranked as the best.

3 Application

In this section, the mentioned methodologies are applied to a real case, which refers to Pamukkale University in Denizli. One of educational foundations operated in Turkey gives scholarships to successful undergraduate students around Turkey every year. Educational foundation is determined the quota of the Faculty of Economics and Administrative Sciences of Pamukkale University as one student. In other words, the number of the students who will benefit from scholarship program is only one for one academic year. Scholar is chosen by a committee. For this purpose, firstly the scholarship committee is created including one representative from educational foundation (DM_1) and three academicians from the faculty (DM_2, DM_3 and DM_4).

The criteria used in this study are determined by the educational foundation that provides the scholarship. The criteria that are used in evaluating the applicants are defined as follows:

Grade Point Average (GPA) of the student (C_1): The student is required to obtain a minimum GPA of 2.0 to get his/her scholarship.

The payment amount of the student for accommodation (C_2): It includes rent of their house or dormitory fee. It is expressed as TRY. If the student lives with his/her family in Denizli, this value will be 0.

The amount of payment, salary or scholarship received by the student from any private or public institution (C_3): It is expressed as TRY. If the student does not get any payment or have any scholarship, this value will be 0.

The marital status and living arrangements of a student's parents (C_4): For this criterion, 1 shows that the student's parents are both living and married to each other whereas 0 shows that the student's parents are divorced or separated.

The number of family member that must be liable to look after (C_5): It shows the number of family member that must be liable to look after by their parents.

The number of the siblings in the family who are still students (C_6): It shows the number of siblings in the family who are still students.

Annual family net income (C_7): It shows the annually financial position of the family, and expressed as TRY.

The amount of rent received by the family from their immovable property (C_8): It is expressed as TRY. If the family does not have any flat, building etc., this value will be 0.

The market value of the automobile that the family owns (C_9): It is expressed as TRY. If family does not own the automobile, this value will be 0.

The selection process begins with finding the weight of each criterion. Firstly, each decision maker identifies his/her best and worst criteria among all criteria shown in Table 5.

Then, each decision maker states pairwise comparisons between the best criterion over all the other criteria, and all the criteria over the worst one, respectively. Saaty's 1 to 9 scale shown in Table 2 is used while making the pairwise comparisons. Table 6 and Table 7 show these pairwise comparisons.

Table 5. The best and the worst criterion/criteria for each decision maker.

Decision Maker	The Best Criterion/Criteria	The Worst Criterion/Criteria
DM_1	C_1	C_9
DM_2	C_1, C_7	C_9
DM_3	C_1, C_4, C_7	C_3, C_9
DM_4	C_1, C_4, C_7	C_9

Table 6. The preference of the best criterion over all the other criteria.

				DM_1					
Best criterion	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1.00	4.00	7.00	3.00	5.00	6.00	2.00	8.00	9.00
				DM_2					
Best criterion	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1, C_7	1.00	6.00	7.00	2.00	4.00	5.00	1.00	7.00	9.00
				DM_3					
Best criterion	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1, C_4, C_7	1.00	5.00	9.00	1.00	7.00	3.00	1.00	3.00	9.00
				DM_4					
Best criterion	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1, C_4, C_7	1.00	2.00	8.00	1.00	4.00	7.00	1.00	4.00	8.00

Table 7. The preferences of all the other criteria over the worst criterion.

DM_1		DM_2		DM_3		DM_4	
	Worst criterion		*Worst criterion*		*Worst criterion*		*Worst criterion*
	C_9		C_9		C_3, C_9		C_9
C_1	9.00	C_1	9.00	C_1	9.00	C_1	8.00
C_2	6.00	C_2	5.00	C_2	5.00	C_2	7.00
C_3	3.00	C_3	4.00	C_3	1.00	C_3	2.00
C_4	7.00	C_4	7.00	C_4	9.00	C_4	8.00
C_5	5.00	C_5	6.00	C_5	3.00	C_5	4.00
C_6	4.00	C_6	5.00	C_6	7.00	C_6	3.00
C_7	8.00	C_7	9.00	C_7	9.00	C_7	8.00
C_8	2.00	C_8	3.00	C_8	7.00	C_8	5.00
C_9	1.00	C_9	1.00	C_9	1.00	C_9	1.00

As shown in Table 5, the decision makers do not have any common decision about the best and the worst criteria. Also, the numbers of best or worst criteria are not unique for some decision makers. In this situation, 9x9 pairwise comparison matrix is completed for every decision maker by the help of secondary comparisons. As an example, 9x9 pairwise comparison matrix of DM_1 is given in Table 8. The best and worst criteria of DM_1 are C_1 and C_9, respectively. The pairwise comparisons of C_1 and C_9 over criteria, primary comparisons, are highlighted in Table 8. The others are secondary comparisons. For instance, C_2 and C_3 are neither best nor worst criteria. We know that $a_{23} = w_2/w_3$, and w_2/w_3 can be found as $(w_B/w_3)/(w_B/w_2)$ in the following:

$$a_{23} = \frac{w_2}{w_3} = \frac{w_B}{w_3} \div \frac{w_B}{w_2} = 7 \div 4 = 1.75$$

The similar secondary comparisons are calculated, and 9x9 pairwise comparison matrix of DM_1 is completed as seen in Table 8. The same procedure is applied for other decision makers. Afterwards, by using Eq.(4) pairwise comparison matrices of four decision makers are aggregated, and the result is shown in Table 9. In the aggregation process, the geometric mean of the pairwise comparison matrices of 4 decision makers is computed. Clearly, an aggregated pairwise comparison matrix is formed by taking the geometric mean of the elements in the same position of 4 comparison matrices in 9x9 size.

The row totals of Table 9 are computed to determine the best and the worst criteria of the aggregated pairwise comparison matrix. The criterion with the highest row total value is considered as the best criterion whereas the criterion with the smallest value among the row totals is also considered as the worst criterion. In this manner, C_1 and C_9 are the best and worst criteria of aggregated pairwise comparison matrix, respectively. The row elements of C_1 and C_9 are used as the Best-to-Others vector and Others-to-Worst vector, respectively. In other words, these values are used as inputs for the model shown in Eq.(6). Then, optimal criteria weights are computed with the model shown in Eq.(6). The results are shown in Table 10. The optimal value of model (ξ^{*L}) is 0.052. In this study, a_{BW} value is computed as 8.74 therefore, this value is rounded up, and it is assumed as a_{BW}=9. While calculating the consistency ratio, the consistency index value corresponding to 9 in Table 3 is used. Consistency ratio proposed by Rezaei [20] is computed as 0.009, and this value is in the acceptable range. After making necessary announcement about the scholarship program in the faculty, 35 students (S_1, S_2, ..., S_{35}) apply for this scholarship. Then, these students fill out the application form including their personal information and the data related with criteria. The data collected from the applicants are tabulated, and utilized as decision matrix of the selection problem. Each student's data with respect to each criterion is shown in Table 11.

The types of criteria used in the study are different from each other. The types of C_1, C_2, C_5 and C_6 are beneficial whereas C_3, C_4, C_7, C_8 and C_9 are non-beneficial criteria. The different types of data in the decision matrix are normalized separately by Eq.(9a)-(9b), and normalized decision matrix is obtained. From now on, the necessary operations for CoCoSo method are applied. Firstly, S_i and P_i values are computed using Eq. (10). Then, k_{ia}, k_{ib}, and k_{ic} values are calculated using Eq. (11)-(13). Finally, ranking score of each student is computed by Eq.(14). All of these values are shown in Table 12. According to Table 12, the highest value belongs to the twelfth student (S_{12}) so it can be said that twelfth student (S_{12}) is the best in terms of fulfilling the needs of the scholarship successfully. In the calculation of the values given in Table 12, the threshold value (λ) is taken as 0.5. In order to check if λ has an effect on the ranking, new rankings are obtained by using different λ values. These rankings and the change in rankings can be observed in Figure 2. When Figure 2 is examined, it is seen that when λ changes, there are slight changes in the rankings. However, S_{12} is in the first place in all rankings.

Table 8. Pairwise comparison matrix of DM_1.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1	4	7	3	5	6	2	8	9
C_2	0.25	1	1.75	0.75	1.25	1.5	0.5	2	6
C_3	0.14	0.57	1	0.43	0.71	0.86	0.29	1.14	3
C_4	0.33	1.33	2.33	1.00	1.67	2.00	0.67	2.67	7
C_5	0.20	0.80	1.40	0.60	1.00	1.20	0.40	1.60	5
C_6	0.17	0.67	1.17	0.50	0.83	1.00	0.33	1.33	4
C_7	0.50	2.00	3.50	1.50	2.50	3.00	1.00	4.00	8
C_8	0.13	0.50	0.88	0.38	0.63	0.75	0.25	1	2
C_9	0.11	0.17	0.33	0.14	0.20	0.25	0.13	0.50	1

Table 9. Aggregated pairwise comparison matrix.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	Total
C_1	1.00	3.94	7.71	1.57	4.86	5.01	1.19	5.09	8.74	39.10
C_2	0.25	1.00	2.53	0.40	1.24	1.27	0.30	1.29	5.69	13.98
C_3	0.13	0.40	1.00	0.20	0.51	0.53	0.15	0.53	2.21	5.67
C_4	0.64	2.51	4.92	1.00	3.11	3.20	0.76	3.25	7.71	27.11
C_5	0.21	0.81	1.96	0.32	1.00	1.03	0.24	1.05	4.36	10.97
C_6	0.20	0.79	1.90	0.31	0.97	1.00	0.24	1.02	4.53	10.95
C_7	0.84	3.31	6.48	1.32	4.09	4.21	1.00	4.28	8.49	34.02
C_8	0.20	0.77	1.87	0.31	0.96	0.98	0.23	1.00	3.81	10.13
C_9	0.11	0.18	0.45	0.13	0.23	0.22	0.12	0.26	1.00	2.70

Table 10. Optimal weight for each criterion found by Eq. (6).

Criterion	w_j	*Criterion*	w_j	*Criterion*	w_j
C_1	0.248	C_4	0.191	C_7	0.243
C_2	0.076	C_5	0.062	C_8	0.059
C_3	0.039	C_6	0.060	C_9	0.022

Table 11. Decision matrix.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
S_1	2.88	120	300	1	5	0	17000	0	0
S_2	2.3	0	0	1	4	2	15000	0	11500
S_3	2.3	264	0	1	4	2	10472	0	9250
S_4	2.3	264	0	1	5	1	8000	0	0
S_5	2.74	120	0	1	3	1	21504	0	0
S_6	2.3	120	0	1	3	1	11999	0	6800
S_7	2.3	0	0	1	4	2	10440	450	0
S_8	2.3	120	0	1	3	1	10800	600	0
S_9	3.16	120	300	1	5	2	9000	0	0
S_{10}	2.69	120	0	1	3	1	5000	0	29500
S_{11}	2.22	264	300	1	7	3	11160	0	17000
S_{12}	3.07	264	0	0	4	1	12000	0	0
S_{13}	2.81	120	300	1	3	0	10000	0	21750
S_{14}	2.3	380	0	1	3	0	4300	0	41000
S_{15}	3.35	300	0	1	3	1	11016	0	0
S_{16}	2.3	120	0	1	2	0	10800	350	0
S_{17}	2.3	120	0	1	4	2	5080	300	8000
S_{18}	2.3	400	300	1	4	1	12000	300	0
S_{19}	2.72	264	300	1	4	0	12528	450	0
S_{20}	2.73	0	0	1	3	1	24000	0	22000
S_{21}	2.78	120	300	1	3	1	12516	420	6500
S_{22}	2.59	350	300	1	3	0	30504	0	20500
S_{23}	2.3	0	0	1	3	1	36000	0	28500
S_{24}	2.3	375	0	1	2	0	11760	600	0
S_{25}	2.83	650	300	1	3	1	10000	0	0
S_{26}	3.1	300	0	1	3	0	10700	0	21500
S_{27}	2.3	400	0	1	3	0	20400	500	0
S_{28}	2.56	0	0	0	2	1	18000	0	10500
S_{29}	3.32	0	300	1	4	2	39600	500	0
S_{30}	2.59	600	300	1	3	1	20064	0	0
S_{31}	2.3	264	0	1	4	2	12000	500	0
S_{32}	3.52	120	0	1	4	1	9600	420	7200
S_{33}	2.67	264	300	1	4	1	13680	380	0
S_{34}	3.35	435	0	1	3	0	22800	0	21500
S_{35}	3.03	300	300	1	2	0	10800	0	0

Table 12. Overall value of each student based on Table 11.

	S_i	P_i	k_{ia}	k_{ib}	k_{ic}	k_i	Ranking
S_1	0.414	5.591	0.025	3.607	0.639	1.811	21
S_2	0.363	6.330	0.028	3.488	0.712	1.821	20
S_3	0.426	7.304	0.032	4.067	0.823	2.118	11
S_4	0.441	7.313	0.033	4.150	0.825	2.151	10
S_5	0.390	7.368	0.033	3.878	0.826	2.050	13
S_6	0.368	7.160	0.032	3.704	0.801	1.967	15
S_7	0.356	6.298	0.028	3.444	0.708	1.802	22
S_8	0.321	6.173	0.027	3.215	0.691	1.704	29
S_9	0.562	6.713	0.031	4.700	0.774	2.316	4
S_{10}	0.478	7.465	0.033	4.396	0.845	2.257	5
S_{11}	0.420	5.871	0.026	3.706	0.670	1.871	18
S_{12}	0.739	8.657	0.039	6.140	1.000	3.017	1
S_{13}	0.412	5.548	0.025	3.587	0.634	1.800	23
S_{14}	0.413	5.366	0.024	3.549	0.615	1.772	27
S_{15}	0.600	7.700	0.035	5.138	0.883	2.560	2
S_{16}	0.313	5.281	0.024	2.969	0.595	1.542	31
S_{17}	0.418	7.251	0.032	4.006	0.816	2.090	12
S_{18}	0.348	6.248	0.028	3.387	0.702	1.776	26
S_{19}	0.374	5.527	0.025	3.370	0.628	1.715	28
S_{20}	0.345	6.438	0.028	3.412	0.722	1.800	24
S_{21}	0.376	6.398	0.028	3.577	0.721	1.861	19
S_{22}	0.257	5.296	0.023	2.653	0.591	1.421	33
S_{23}	0.177	5.891	0.025	2.338	0.646	1.341	35
S_{24}	0.312	4.404	0.020	2.762	0.502	1.396	34

Table 12. Continued.

	S_i	P_i	k_{ia}	k_{ib}	k_{ic}	k_i	Ranking
S_{25}	0.510	6.629	0.030	4.385	0.760	2.189	8
S_{26}	0.523	6.692	0.030	4.472	0.768	2.227	7
S_{27}	0.278	6.132	0.027	2.961	0.682	1.602	30
S_{28}	0.539	6.534	0.030	4.529	0.753	2.237	6
S_{29}	0.307	4.780	0.021	2.819	0.541	1.447	32
S_{30}	0.389	6.434	0.029	3.658	0.726	1.895	16
S_{31}	0.372	7.197	0.032	3.734	0.806	1.981	14
S_{32}	0.588	7.649	0.035	5.060	0.877	2.526	3
S_{33}	0.384	6.454	0.029	3.633	0.728	1.887	17
S_{34}	0.503	6.660	0.030	4.354	0.762	2.180	9
S_{35}	0.469	4.784	0.022	3.737	0.559	1.798	25

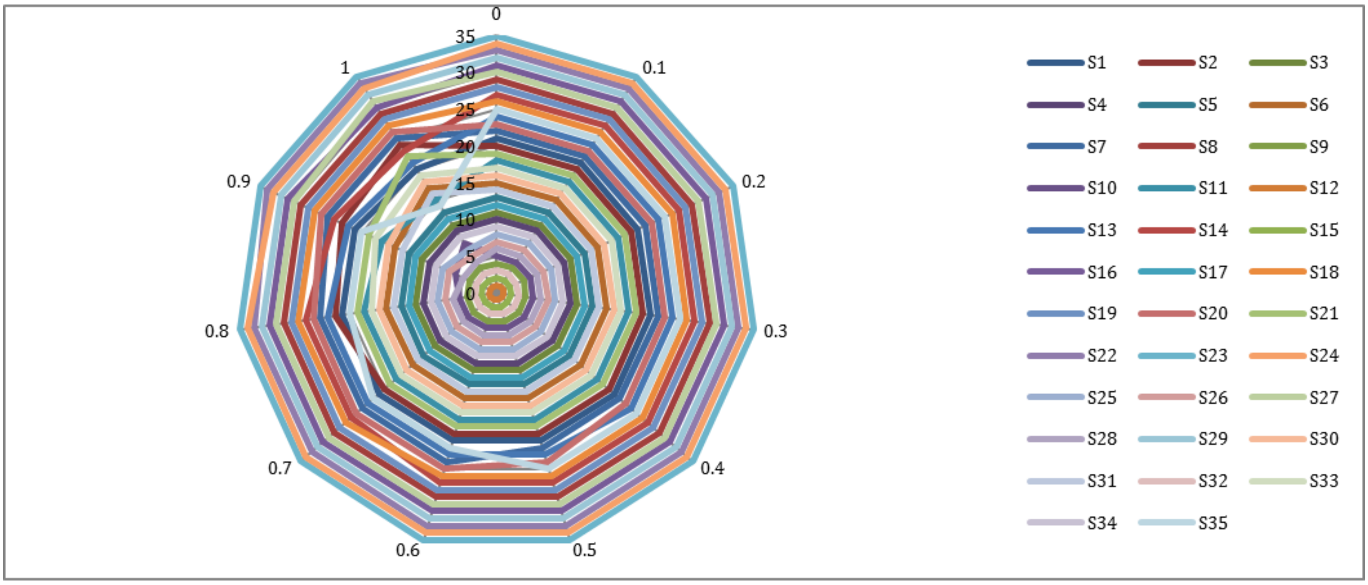

Figure 2. The effects of λ on the rankings.

4 Discussion

In this study, scholarship offered by an educational foundation is allocated to the best-suited student among multiple candidates effectively. In this manner identifying, weighting and evaluating the competing applicants are assumed as an MCDM problem. For solving this problem, a selection process based on two MCDM methods, BWM and CoCoSo, is developed.

Firstly, scholarship selection criteria are determined by the committee. In this study, nine criteria are discussed for the problem. Then, each decision maker separately identifies his/her best and worst criteria. In this situation, they are not unique for a decision maker and also, the decision makers do not reach any consensus about the best or worst criterion. These situations are the main characteristics of this study. To overcome this situation and solve the problem, secondary comparisons between criteria are considered. After computing the secondary comparisons and completing the each decision maker's pairwise comparison matrix, they are aggregated with geometric mean. The necessary operations are performed with aggregated pairwise comparison matrix. The best and worst criteria are determined by taking the row total of aggregated pairwise comparison matrix. In our study, *grade point average of the student* and *the market value of the automobile that the family owns* are derived from the aggregated pairwise comparison matrix as the best and worst criteria, respectively. From now on, the necessary mathematical models of BWM are developed, and criteria weights are computed. The results of BWM indicate that the most important criterion in selecting an appropriate scholar is *grade point average of the student* with an importance level of 0.264. This criterion is followed by *annual family net income* with an importance level of 0.243. We can say that they are very close in terms of their importance levels. Actually, this result is not too surprising for us, because *annual family net income* is among the best criteria of three decision makers. On the other hand, *the market value of the automobile that the family owns* is the least important criterion with an importance level of 0.022. Consistency ratio proposed by Rezaei [20] is also computed in the study, and this value (0.009) is assumed as acceptable. Performing BWM for scholarship selection problem is thought as appropriate method. As in our case study, the scholarship is provided by an educational foundation. This educational foundation also wants to determine the importance levels of criteria while selecting the best student among the scholarship applicants. In this sense, it seems quite reasonable to use a subjective weighting method. Simplicity of the method performed is also important for decision makers, and it comes from the decision maker's role on the selection process. In this method, decision makers are only asked to compare the best and the worst criteria with the others. So, the numbers of pairwise comparisons between the criteria are decreased to *2n-3*, if there are *n* criteria in the problem [20]. The time requiring for solving the problem is also decreased. To understand and fill the pairwise comparison matrix is easy for the decision makers. In such problems, each decision maker's pairwise comparisons can be aggregated with different ways. In further studies, criteria such as the disability status of students, students coming to university for education from low-income regions, and the scores of students in the university entrance exam can be added. In this case, the selection problem will become more complex as the number of criteria increases. When BWM is compared to AHP, BWM produces more consistent results for large and complex decision problem like our case study including nine criteria and four decision makers.

Determining the importance levels of the scholarship selection criteria is not sufficient to solve the scholarship selection problem. It is absolutely necessary to select among the students who apply the scholarship. In this study, the CoCoSo method is used as the selection method. An important feature that makes the CoCoSo method superior to other available MCDM methods is its simplicity and user friendly. It only requires the criteria weights and performances of the alternatives with respect to criteria. Types of criteria as beneficial and non-beneficial are considered. Students are ranked efficiently with CoCoSo method which considers criteria weights derived from BWM and performances of students with respect to criteria. The results of the method suggest that twelfth student (S_{12}) is the best in terms of performing the needs of the scholarship successfully. In this sense, the result includes both the importance level of the criteria determined by the scholarship provider and the information of the student applying for the scholarship, as stated before. From this point of view, the integration of BWM and CoCoSo methods is very effective for the decision committee. It should also be noted that the results of this study are valid for only this faculty and the specified academic term. If the decision makers participating in the study, the students applying for the scholarship, data of the applicants, and the criteria change, the results of this study will also change. As Akıllı and İpekçi Çetin [97] stated, increasing the degree of expertise of the decision makers who are effective in determining the selection criteria and the number of decision makers participating in the decision process will increase the reliability of the results.

5 Conclusion

In this study, BWM is integrated with CoCoSo method for scholarship selection. To present the applicability of integrated methodology, a real case study is solved, and results are given above sections. The contributions of this study to the literature can be summarized in the following:

- To the best of our knowledge, the scholarship selection problem is solved with the integration of BWM and CoCoSo methods for the first time in the literature,
- The scholarship selection problem designed as a group decision-making problem,
- The weights of selection criteria are computed subjectively by using pairwise comparisons. In this manner, BWM is performed to eliminate the drawbacks of AHP method,
- The main characteristic of the handled problem is that the best and worst criteria are not unique for each selection committee member. This situation is overcome by using secondary comparisons. Although the use of secondary comparisons seems to complicate the method, secondary comparisons are calculated using simple mathematical operations, not pairwise comparisons of decision makers. The basis for these calculations is the best and worst criteria that are identified by the decision makers,
- Another characteristic of handled problem is that the decision makers do not reach any consensus about the best or worst criterion. This situation is addressed by using aggregation concept. The common best and worst criteria are specified after getting aggregated pairwise comparison matrix,
- The selection of best scholar among scholars who fulfil all criteria is performed by CoCoSo method. With this selection, it is thought that an easy-to-understand and practical methodology has been developed for decision makers on this subject.

BWM and CoCoSo methods are thought as appropriate methods for weighting and ranking the candidates or alternatives because of satisfactory results. In future academic terms, the same problem may be updated by changing the numbers of criteria, students and decision makers in the committee. Different aggregation ways may be tried. Fuzzy extensions of these methods may be applied. Finally, these methods are applicable to other management problems.

6 Author contribution statements

In the scope of this study, Esra AYTAÇ ADALI, in the formation of the idea, the literature review, the construction of the theoretical background, performing analyzes and the writing and checking the article; Atalay ÇAĞLAR, in the formation of the idea, the literature review, the construction of the theoretical background, performing analyzes and the writing and checking the article, were contributed.

7 Ethics committee approval and conflict of interest statement

Ethics committee permission is not required for the article prepared.

There is no conflict of interest with any person/institution in the article prepared.

8 References

[1] Indriyanti AD, Prehanto DR, Prismana IGLEP, Sujatmiko B, Fikandda J. "Simple additive weighting algorithm to aid administrator decision making of the underprivileged scholarship". *Journal of Physics: Conference Series*, 1402(6), 1-7, 2019.

[2] Mardhiyyah R, Sejati RHP, Ratnasari D. "A decision support system of scholarship grantee selection using Moora". *International Journal of Applied Business and Information Systems*, 3(1), 21-27, 2019.

[3] Hasan P, Utami E, Yunita S, Pawan E. "Selection of scholarship acceptance using AHP and TOPSIS methods". *IEEE 2019 International Conference on Information and Communications Technology,* Yogyakarta, Indonesia, 24-25 July 2019.

[4] Marfuah, Widiantoro S. "The implementation of Analytical Hierarchy Process method for outstanding achievement scholarship reception selection at Universal University of Batam". *IOP Conference Series: Earth and Environmental Science*, 97(1), 1-9, 2017.

[5] Yeh CH. "A problem-based selection of multi-attribute decision-making methods". *International Transactions in Operational Research*, 9(2), 169-181, 2002.
[6] Yeh CH. "The selection of multiattribute decision making methods for scholarship student selection". *International Journal of Selection and Assessment*, 11(4), 289-296, 2003.
[7] Uyun S, Riadi I. "A fuzzy TOPSIS multiple-attribute decision making for scholarship selection". *Telkomnika*, 9(1), 37-46, 2011.
[8] Wimatsari GAN, Putra KGD, Buana PW. "Multi-attribute decision making scholarship selection using a modified fuzzy TOPSIS". *International Journal of Computer Sciences*, 10(2), 309-317, 2013.
[9] Saptarini NGAPH, Prihatini PM. "Decision support system for scholarship in Bali state polytechnic using AHP and TOPSIS". *International Conference on Information Technology and Business (ICITB),* Bandar Lampung, Indonesia, 20-21 August 2015.
[10] Purba RA, Sembiring J. "Selection of scholarship recipients by using promethee method in Polytechnic Unggul LP3M Medan". *International Seminar on Application for Technology of Information and Communication (ISemantic),* Semarang, Indonesia, 5-6 August 2016.
[11] Mesran KT, Sianturi RD, Waruwu FT, Siahaan AP. "Determination of education scholarship recipients using preference selection index". *International Journal of Scientific Research in Science and Technology*, 3(6), 230-234, 2017.
[12] Puspitasari TD, Sari EO, Destarianto P, Riskiawan HY. "Decision support system for determining scholarship selection using an analytical hierarchy process". *Journal of Physics: Conference Series,* 953 (1), 1-5, 2018.
[13] Rizana AF, Soesanto RP. "Design of decision support system application for determining scholarship grantee using Analytical Hierarchy Process and Factor Rating". *International Conference on Industrial Enterprise and System Engineering,* Yogyakarta, Indonesia, 21-22 November 2018.
[14] Mahmud N, Muhammat Pazil NS, Mazlan UH, Jamaluddin SH, Che Hasan NN. *Scholarship Eligibility and Selection: A Fuzzy Analytic Hierarchy Process Approach*. Editors: Saian R, Abbas M. Proceedings of the Second International Conference on the Future of ASEAN (ICoFA), 175-183, Singapore, Springer, 2018.
[15] Anamisa DR, Rachmad A, Putro SS, Jauhari A, Khozaimi A, Pujiastutik R, Rahmanita E. "The selection system of student scholarship based on simple additive weighting and technique for order preference by similarity to ıdeal solution method". *1st International Conference on Computer Science and Engineering Technology,* Kudus, Indonesia, 25 October 2018.
[16] Mufizar T, Mulyani EDS, Wiyono RA, Arifiana W. "A combination of Multi Factor Evaluation Process (MFEP) and the Distance to the Ideal Alternative (DIA) methods for majors selection and scholarship recipients in SMAN 2 Tasikmalaya". *6th International Conference on Cyber and IT Service Management (CITSM)*, Indonesia, 7-9 August 2018.
[17] Utami A, Ruskan EL. "Development of decision support system for selection of Yayasan alumni scholarship using MOORA method". *Advances in Intelligent Systems Research*, 172, 706-710, 2020.
[18] Oktaviani O, Triayudi A, Solihati ID. "Comparison of weighted product method and simple additive weighting in scholarship recipient selection: comparison of weighted product method and simple additive weighting in scholarship recipient selection". *Jurnal Mantik*, 3(4), 337-347, 2020.
[19] Rafida V, Widiyatni W, Harpad B, Yulsilviana E. "Implementation of multi-attribute rating technique simple in selection of acceptance scholarship of PMDK (Case Study: STMIK Widya Cipta Dharma)". *International Journal of Modern Education & Computer Science*, 13(1), 22-33, 2021.
[20] Rezaei J. "Best-worst multi-criteria decision-making method". *Omega*, *53*, 49-57, 2015.
[21] Saaty T. *The Analytic Hierarchy Process: Planning, Priority Setting, Resources Allocation*. 1st ed. London, England, McGraw-Hill, 1980.
[22] Bozbura FT, Beskese A. "Prioritization of organizational capital measurement indicators using fuzzy AHP". *International Journal of Approximate Reasoning*, 44(2), 124-147, 2007.
[23] Oğuztimur S. "Why fuzzy analytic hierarchy process approach for transport problems?". *51st European Regional Science Association Conference*, Barcelona, Spain, 30 August-2 September 2011.
[24] Yazdani M, Zarate P, Zavadskas EK, Turskis Z. "A Combined Compromise Solution (CoCoSo) method for multi-criteria decision-making problems". *Management Decision*, 57(9), 2501-2519, 2018.
[25] Peng X, Huang H. "Fuzzy decision making method based on CoCoSo with CRITIC for financial risk evaluation". *Technological and Economic Development of Economy*, 26(4), 695-724, 2020.
[26] Mou Q, Xu Z, Liao H. "An intuitionistic fuzzy multiplicative best-worst method for multi-criteria group decision making". *Information Sciences*, 374, 224-239, 2016.
[27] Ghaffari S, Arab A, Nafari J, Manteghi M. "Investigation and evaluation of key success factors in technological innovation development based on BWM". *Decision Science Letters*, 6(3), 295-306, 2017.
[28] Bezerianos G. Market Choice Opportunities For Gas Sweetening Technologies. Ph.D Dissertation, Delft University of Technology, Delft, Netherlands, 2016.
[29] Rezaei J, Wang J, Tavasszy L. "Linking supplier development to supplier segmentation using Best Worst Method". *Expert Systems with Applications*, 42(23), 9152-9164, 2015.
[30] Koçak H, Çağlar A, Öztaş GZ. "Euclidean Best–Worst method and its application", *International Journal of Information Technology & Decision Making*, 17(5), 1587-1605, 2018.
[31] Rezaei J, Nispeling T, Sarkis J, Tavasszy L. "A supplier selection life cycle approach integrating traditional and environmental criteria using the best worst method". *Journal of Cleaner Production*, 135, 577-588, 2016.
[32] Ren J, Liang H, Chan FT. "Urban sewage sludge, sustainability, and transition for Eco-City: Multi-Criteria sustainability assessment of technologies based on best-worst method". *Technological Forecasting and Social Change*, 116, 29-39, 2016.

[33] Bakker SW. Improving The Performance of the Trolley Supply Chain With a Focus On Visibility Using Best-Worst Multi-Criteria Decision Making Method. MSc Thesis, Delft University of Technology, Amsterdam, Holland, 2014.

[34] Sadaghiani S, Ahmad KW, Rezaei J, Lóránt Tavasszy L. "Evaluation of external forces affecting supply chain sustainability in oil and gas ındustry using Best Worst Method". *International Mediterranean Gas and Oil Conference (MedGO)*, Mechref, Lebanon, 16-18 April 2015.

[35] Rezaei J, Hemmes A, Tavasszy L. "Multi-criteria decision-making for complex bundling configurations in surface transportation of air freight". *Journal of Air Transport Management*, 61, 95-105, 2016.

[36] Gupta H, Barua MK. "Identifying enablers of technological innovation for Indian MSMEs using best–worst multi criteria decision making method". *Technological Forecasting and Social Change*, 107, 69-79, 2016.

[37] Abadi F, Sahebi I, Arab A, Alavi A, Karachi H. "Application of best-worst method in evaluation of medical tourism development strategy". *Decision Science Letters*, 7(1), 77-86, 2018.

[38] Ecer F. "Sustainability assessment of existing onshore wind plants in the context of triple bottom line: a Best-Worst Method (BWM) based MCDM framework". *Environmental Science and Pollution Research*, 28, 19677-19693, 2021.

[39] Ulutaş A. "The analysis of the importance of the criteria used in the selection of transport vehicle according to cargo companies by BWM". *Equinox Journal of Economics Business and Political Studies*, 7(2), 127-140, 2020.

[40] Bilgiç S, Torğul B, Paksoy T. "Sürdürülebilir enerji yönetimi için BWM yöntemi ile yenilenebilir enerji kaynaklarının değerlendirilmesi". *Verimlilik Dergisi,* 2, 95-110, 2021.

[41] Arsu T, Uğuz Arsu Ş. "Personel seçim sürecinde kullanılan kriterlerin Best-Worst Metodu (BWM) ile değerlendirilmesi". *Üçüncü Sektör Sosyal Ekonomi Dergisi*, 56(3), 1949-1967, 2021.

[42] Öz İ. "Decision making in evaluation and selection of launch site with the best and worst method". *Gazi University Journal of Science*, 35(4), 1521-1533, 2022.

[43] Akyüz G, Tosun Ö, Aka S. "Performance evaluation of non-life insurance companies with Best-Worst Method and TOPSIS". *Uluslararası Yönetim İktisat ve İşletme Dergisi*, 16(1), 108-125, 2020.

[44] You X, Chen T, Yang Q. "Approach to multi-criteria group decision-making problems based on the Best-Worst-Method and ELECTRE method". *Symmetry*, 8(9), 1-16, 2016.

[45] Serrai W, Abdelli A, Mokdad L, Hammal Y. "An efficient approach for Web service selection". *Computers and Communication (ISCC),* Messina, Italy, 27-30 June 2016.

[46] Abdulkareem KH, Arbaiy N, Zaidan AA, Zaidan BB, Albahri OS, Alsalem MA, Salih MM. "A novel multi-perspective benchmarking framework for selecting image dehazing intelligent algorithms based on BWM and group VIKOR techniques". *International Journal of Information Technology & Decision Making*, 19, 1-49, 2020.

[47] Chitsaz N, Azarnivand A. "Water scarcity management in arid regions based on an extended multiple criteria technique". *Water Resource Management*, 31, 233-250, 2017.

[48] Guo S, Zhao H. "Fuzzy best-worst multi-criteria decision-making method and its applications". *Knowledge-Based Systems*, 121, 23-31, 2017.

[49] Ketabchi R, Ghaeli M. "An application of fuzzy BWM for risk assessment in offshore oil projects". *Journal of Project Management*, 4(3), 233-240, 2019.

[50] Xu Y, Zhu X, Wen X, Herrera-Viedma E. "Fuzzy Best-Worst Method and its application in initial water rights allocation". *Applied Soft Computing*, 101, 1-15, 2021.

[51] Aboutorab H, Saberi M, Asadabadi MR, Hussain O, Chang E. "ZBWM: The Z-number extension of Best Worst Method and its application for supplier development". *Expert Systems with Applications*, 107, 115-125, 2018.

[52] Amoozad Mahdiraji H, Arzaghi S, Stauskis G, Zavadskas EK. "A hybrid fuzzy BWM-COPRAS method for analyzing key factors of sustainable architecture". *Sustainability* 10(5), 1-26, 2018.

[53] Parhizgarsharif A, Lork A, Telvari A. "A hybrid approach based on the BWM-VIKOR and GRA for ranking facility location in construction site layout for Mehr project in Tehran". *Decision Science Letters*, 8(3), 233-248, 2019.

[54] Kolagar M. "Adherence to urban agriculture in order to reach sustainable cities; a BWM– WASPAS approach". *Smart Cities*, 2(1), 31-45, 2019.

[55] Arslanhan H, Tosun Ö. "Ulaştırma modu seçimi probleminin bütünleşik en iyi-en kötü ve WASPAS yöntemleriyle çözülmesi". *Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi*, 27(1), 13-23, 2021.

[56] Bahrami Y, Hassani H, Maghsoudi A. "BWM-ARAS: A new hybrid MCDM method for Cu prospectivity mapping in the Abhar area, NW Iran". *Spatial Statistics*, 33, 1-23, 2019.

[57] Çakır E, Can M. "Best-worst yöntemine dayalı ARAS yöntemi ile dış kaynak kullanım tercihinin belirlenmesi: turizm sektöründe bir uygulama". *Atatürk Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, 23(3), 1273-1300, 2019.

[58] Çalık A. "Hedef pazar seçimi için hibrit BWM-ARAS karar verme modeli". *Manisa Celal Bayar Üniversitesi Sosyal Bilimler Dergisi*, 18(3), 196-210, 2020.

[59] Kolagar M, Hosseini SMH, Felegari R, Fattahi P. "Policy-making for renewable energy sources in search of sustainable development: a hybrid DEA-FBWM approach". *Environment Systems and Decisions*, 40, 485-509, 2019.

[60] Wu Q, Zhou L, Chen Y, Chen H. "An integrated approach to green supplier selection based on the interval type-2 fuzzy best-worst and extended VIKOR methods". *Information Sciences*, 502, 394-417, 2019.

[61] Liu A, Ji X, Lu H, Liu H. "The selection of 3PRLs on self-service mobile recycling machine: Interval-valued pythagorean hesitant fuzzy best-worst multi-criteria group decision-making". *Journal of Cleaner Production*, 230, 734-750, 2019.

[62] Behzad M, Zolfani SH, Pamucar D, Behzad M. "A comparative assessment of solid waste management performance in the Nordic countries based on BWM-EDAS". *Journal of Cleaner Production*, 266, 1-11, 2020.

[63] Muravev D, Mijic N. "A novel integrated provider selection multicriteria model: the BWM MABAC model". *Decision Making: Applications in Management and Engineering*, 3(1), 60-78, 2020.

[64] Telli G, Ayçin E. "Öğretmen seçim sürecinde en iyi-en kötü ve Mabac yöntemlerinin bütünleşik olarak kullanılması". *TroyAcademy,* 6, 733-750, 2021.

[65] Özdağoğlu A, Keleş MK, Işıldak B. "Isparta Süleyman Demirel havalimanını kullanan havayolu firmaları performanslarının BWM, MAIRCA VE MABAC ile değerlendirilmesi". *Uluslararası İktisadi ve İdari İncelemeler Dergisi*, 29, 175-194, 2020.
[66] Nabeeh NA, Abdel-Monem A, Abdelmouty A. "A novel methodology for assessment of hospital service according to BWM, MABAC, PROMETHEE II". *Neutrosophic Sets and Systems*, 31(1), 63-79, 2020.
[67] Mohammadi M, Rezaei J. "Bayesian best-worst method: A probabilistic group decision making model". *Omega*, 96, 1-8, 2020.
[68] Akbari R, Dabbagh R, Ghoushchi SJ. "HSE risk prioritization of molybdenum operation process using extended FMEA approach based on Fuzzy BWM and Z-WASPAS". *Journal of Intelligent & Fuzzy Systems*, 38(4), 5157-5173, 2020.
[69] Ishizaka A, Resce G. "Best-Worst PROMETHEE method for evaluating school performance in the OECD's PISA project". *Socio-Economic Planning Sciences*, 73, 1-7, 2021.
[70] Karakış E. "BWM ve bulanık TODIM yöntemleri ile perakende sektöründe tedarikçi seçiminin gerçekleştirilmesi". *Uluslararası İktisadi ve İdari İncelemeler Dergisi*, 34, 37-60, 2022.
[71] Yucesan M, Gul M, Celik E. "A holistic FMEA approach by fuzzy-based Bayesian network and best–worst method". *Complex and Intelligent Systems,* 7, 1547-1564, 2021.
[72] Zolfani SH, Chatterjee P, Yazdani M. "A structured framework for sustainable supplier selection using a combined BWM-CoCoSo model". *International Scientific Conference in Business, Management and Economics Engineering,* Vilnius, Lithuania, 9-10 May 2019.
[73] Alrasheedi M, Mardani A, Mishra AR, Streimikiene D, Liao H, Al-nefaie AH. "Evaluating the green growth indicators to achieve sustainable development: A novel extended interval-valued intuitionistic fuzzy-combined compromise solution approach". *Sustainable Development*, 29(1), 120-142, 2021.
[74] Torkayesh AE, Pamucar D, Ecer F, Chatterjee P. "An integrated BWM-LBWA-CoCoSo framework for evaluation of healthcare sectors in Eastern Europe". *Socio-Economic Planning Sciences*, 78, 1-12, 2021.
[75] Ecer F, Pamucar D. "Sustainable supplier selection: A novel integrated fuzzy best worst method (F-BWM) and fuzzy CoCoSo with Bonferroni (CoCoSo'B) multi-criteria model". *Journal of Cleaner Production*, 266, 1-18, 2020.
[76] Zavadskas EK, Turskis Z, Antucheviciene J, Zakarevicius A. "Optimization of weighted aggregated sum product assessment". *Elektronika ir elektrotechnika*, 122(6), 3-6, 2012.
[77] Aytekin A, Gündoğdu HG. "OECD ve AB üyesi ülkelerin sürdürülebilir yönetişim düzeylerine göre SWARA tabanlı TOPSIS-SORT-B ve WASPAS yöntemleriyle incelenmesi". *Öneri Dergisi*, 16(56), 943-971, 2021.
[78] Ozdagoglu A, Ulutas A, Keles MK. "The ranking of Turkish universities with CoCoSo and MARCOS". *Journal of Economics, Business and Organization Research*, 374-392, 2020.
[79] Khan S, Haleem A. "Investigation of circular economy practices in the context of emerging economies: a CoCoSo approach". *International Journal of Sustainable Engineering*, 14(3), 357-367, 2021.
[80] Erceg Ž, Starcevic V, Pamucar D, Mitrovic G, Stevi´c Ž, Žiki´c S. "A new model for stock management in order to rationalize costs: ABC-FUCOM-interval rough CoCoSo model". *Symmetry*, 11, 1-29, 2019.
[81] Barua A, Jeet S, Kumar Bagal D, Satapathy P, Kumar Agrawal P. "Evaluation of mechanical behavior of hybrid natural fiber reinforced nano sic particles composite using hybrid Taguchi-Cocoso method". *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, 8(10), 3341-3345, 2019.
[82] Wen Z, Liao H, Mardani A, Al-Barakati A. "A hesitant fuzzy linguistic Combined Compromise Solution method for multiple criteria decision making". *International Conference on Management Science and Engineering Management,* Ontario, Canada, 5-8 August 2019.
[83] Ecer F, Pamucar D. "Sustainable supplier selection: A novel integrated fuzzy best worst method (F-BWM) and fuzzy CoCoSo with Bonferroni (CoCoSo'B) multi-criteria model". *Journal of Cleaner Production*, 266, 1-18, 2020.
[84] Akgül Y. "Borsa İstanbul'da işlem gören ticari bankaların finansal performansının bütünleşik CRITIC CoCoSo modeliyle analizi". *Ekonomi ve Finansal Araştırmalar Dergisi*, 3(2), 71-90, 2022.
[85] Peng X, Zhang X, Luo Z. "Pythagorean fuzzy MCDM method based on CoCoSo and CRITIC with score function for 5G industry evaluation". *Artificial Intelligence Review*, 53, 3813–3847, 2020.
[86] Peng X, Smarandache F. "A decision-making framework for China's rare earth industry security evaluation by neutrosophic soft CoCoSo method". *Journal of Intelligent & Fuzzy Systems*, 39(5), 7571-7585, 2020.
[87] Ulutaş A, Karakuş CB, Topal A. "Location selection for logistics center with fuzzy SWARA and CoCoSo methods". *Journal of Intelligent & Fuzzy Systems*, 38(4), 4693-4709, 2020.
[88] Stanujkic D, Popovic G, Zavadskas EK, Karabasevic D, Binkyte-Veliene A. "Assessment of progress towards achieving sustainable development goals of the "Agenda 2030" by using the CoCoSo and the Shannon Entropy methods: the case of the EU Countries". *Sustainability*, 12(14), 1-16, 2020.
[89] Topal A. "Çok kriterli karar verme analizi ile elektrik üretim şirketlerinin finansal performans analizi: Entropi tabanlı CoCoSo yöntemi". *Business and Management Studies: An International Journal*, 9(2), 532-546, 2021.
[90] Lai H, Liao H, Wen Z, Zavadskas EK, Al-Barakati A. "An improved CoCoSo Method with a maximum variance optimization model for cloud service provider selection". *Engineering Economics*, 31(4), 411-424, 2020.
[91] Pala O. "BIST inşaat endeksinde bütünleşik CCSD-COCOSO tabanlı finansal performans analizi". *Afyon Kocatepe Üniversitesi Sosyal Bilimler Dergisi*, 23(4), 1500-1513, 2021.
[92] Liao H, Qin R, Wu D, Yazdani M, Zavadskas E.K. "Pythagorean fuzzy combined compromise solution method integrating the cumulative prospect theory and combined weights for cold chain logistics distribution center selection". *International Journal of Intelligent Systems*, 35(12), 2009-2031, 2020.
[93] Luo Y, Zhang X, Qin Y, Yang Z, Liang Y. "Tourism attraction selection with sentiment analysis of online reviews based on probabilistic linguistic term sets and the IDOCRIW-COCOSO model". *International Journal of Fuzzy Systems*, 23(1), 295-308, 2021.

[94] Vikas C, Mishra A. "Analyzing the critical success enablers of industry 4.0 using hybrid fuzzy AHP-CoCoSo method". *Journal of Industrial Integration and Management*, 7(4), 493-514, 2022.

[95] Gençkaya Ö, Gündoğdu HG, Aytekin A. "Büyükşehir belediyeleri web sitelerinin yönetişim ilkeleri açısından değerlendirilmesi". *Eskişehir Osmangazi Üniversitesi İktisadi ve İdari Bilimler Dergisi*, 16(3), 705-726, 2021.

[96] Peng X, Krishankumar R, Ravichandran KS. "A novel interval-valued fuzzy soft decision-making method based on CoCoSo and CRITIC for intelligent healthcare management evaluation". *Soft Computing*, 25, 4213-4241, 2021.

[97] Akıllı K, İpekçi Çetin E. "Selection of scholarship students in higher education with VIKOR method". *International Journal of Assessment Tools in Education*, 7(3), 379-391, 2020.