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Research Article

The use of Different Criteria Weighting and Multi-Criteria Decision Making Methods for University Ranking: Two-Layer Copeland

Üniversite Sıralaması İçin Farklı Kriter Ağırlıklandırma ve Çok Kriterli Karar Verme Yöntemlerinin Birlikte Kullanılması: İki Katmanlı Copeland

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Abstract : Multi-criteria methods are gaining attention in academia and industry applications for effective decision making. Although there are many multi-criteria decision making (MCDM) methods, none of these methods are perfect and should be chosen according to the decision problem. Choosing the necessary decision support method to find the right solution that suits the decision maker becomes an important problem. In order to solve this problem, methods such as Copeland and Borda, which combine the results of different MCDM methods, are available and widely used. In this study, a university satisfaction ranking is performed by combining the results of different MCDM and different criteria weighting methods. Tests were conducted on student satisfaction data of 20 foundation universities in Turkey. It is investigated that the approach called Two-layer Copeland can be used as a benchmark in MCDM problems and the results are shown comparatively

Keywords: Multi criteria decision making, decision making, university, Copeland, Borda.

Özet : Çok kriterli yöntemler, etkili karar verme için akademi ve endüstri uygulamalarında dikkat çekmektedir. Birçok çok kriterli karar verme (ÇKKV) yöntemi olmasına rağmen, bu yöntemlerin hiçbiri mükemmel değildir ve karar problemine göre seçilmelidir. Karar vericiye uygun olan doğru çözümü bulmak için gerekli karar destek yöntemini seçmek önemli bir sorun haline gelmektedir. Bu sorunu çözmek için farklı ÇKKV yöntemlerinin sonuçlarını birleştiren Copeland ve Borda gibi yöntemler mevcuttur ve yaygın olarak kullanılmaktadır. Bu çalışmada, farklı ÇKKV ve farklı kriter ağırlıklandırma yöntemlerinin bir arada kullanılarak üniversite memnuniyet sıralaması gerçekleştirilmiştir. Türkiye'deki 20 vakıf üniversitesinin öğrenci memnuniyeti verileri üzerinde testler gerçekleştirilmiştir. Two-layer Copeland olarak adlandırılan yaklaşımın, ÇKKV problemlerinde bir ölçüt olarak kullanılabileceği araştırılmış ve sonuçlar karşılaştırılmalı olarak gösterilmiştir.

Anahtar Kelimeler: Çok kriterli karar verme, karar verme, üniversite, Copeland, Borda.

1. Introduction

Decision making is the act of choosing between an option or situation. Formally, a decision can be defined as a choice made based on available information or a method of action to solve a particular decision problem. Since decision making requires an important intellectual process, it can be said that this is the most important feature that distinguishes humans from other beings. The decision-making process is related to the handling of the problem from different criteria, not from a single point of view. This is an approach to considering the pros and cons of multiple perspectives, in other words the domain of Multi-Criteria Decision Making (MCDM). MCDM is closely related to how individuals make decisions. Therefore, MCDM components can be expressed as alternatives, criteria, and decision makers. Alternatives: A list of options for MCDM, called solutions or courses of action. These alternatives are options to be evaluated to solve a particular problem or achieve a particular goal. Criteria: criteria or standards used to evaluate alternatives. Criteria can be based on various attributes, characteristics or performance measures and represents important factors in the decision-making process. Criteria could be factors such as cost, efficiency, sustainability, safety, time, quality. Decision Maker (DM): DM is a person who takes the decisions and evaluates the alternatives and criteria in the MCDM process. The Decision Maker can be an individual, a group or an organization depending on a particular problem or decision situation (Greco et al., 2005).

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Although there are many multi-criteria decision making (MCDM) methods, it is important that not all of these methods are perfect and should be chosen depending on which decision problem we are dealing with. (Guitouni & Martel, 1998). If the multi-criteria methods applied for the decision problem different results, especially inconsistent results, the accuracy of the results may be doubted. In this case, it becomes an important problem for the decision maker to choose the necessary decision support method of the right solution (Cinelli et al., 2020; Roy, 1996).

Copeland and Borda are the most used methods to combine the results of different MCDM methods. By comparing these methods with the ranking results of different MCDM methods, a final ranking result is obtained with a reward penalty mechanism. In the literature, there are many studies in which these methods and the results are combined. For the "sustainable cathode material selection" problem, a hybrid model was created with data envelopment analysis using the subjective, objective, and "combined weights" methods, and it was observed that the hybrid model gave more effective results when the comparisons made. It was stated that the use of both subjective and objective weighting methods together were effective in these results (Tajik et al., 2023). LOPCOW and EDAS methods were used to examine the early impact of COVID-19 on the performance of firms in the FMCG and durable goods sectors in emerging markets, and the results over a seven-year period were combined with the Copeland and Board count methods (Biswas, Bandyopadhyay, & Mukhopadhyaya, 2022). The authors used the same framework method to create a portfolio with stock selection. They also used the Simple Additive Weighting (SAW) method along with the Copeland and Borda method to combine the results (Biswas, Bandyopadhyay, Pamucar, et al., 2022). In the MCDM method developed to reduce the intrusion of sea water on the coasts of Tehran, the Rank Average Method was used together with the Copeland and Borda methods (Nasiri et al., 2021). In the study where a customer recommendation system was developed using the CRITIC weighting method and five MCDM methods, the Copeland method was used for the final result (Baczkiewicz et al., 2021). In the study, in which different criterion weighting and MCDM methods are used for car production location selection, the results are combined with the Copeland method (Şahin, 2021). In the study where environmental impact assessment was carried out using MCDM methods, the results were combined with Borda, Copeland, and Kohler methods (Mohebali et al., 2020). The bank performances were evaluated by combining Analytic hierarchy process (AHP) and modified digital logic (MDL) techniques with Fuzzy TOPSIS and Fuzzy VIKOR, and then the results were combined with Copeland method (Beheshtinia & Omidi, 2017) the MCDM technique was implemented in four banks in Iran as a pilot. First, proper criteria for banking industry are identified considering BSC and CSR. Consequently, analytic hierarchy process (AHP. The performance of Information and Communication Technologies Projects were weighted by different decision makers using the AHP method. Then, the results with different rankings made with TOPSIS were combined with Copeland (Setiawan et al., 2016). In the study, in which four hospitals in Iran were ranked with different MCDM methods and the results were combined with the Copeland method, another hybrid model was proposed (Torkzad & Beheshtinia, 2019). For the purpose of prioritization for road maintenance, the AHP method was used to weight the criteria and the ELECTRE II, ELECTRE III and ELECTRE IV methods were used to rank the roads. Sequencing results combined with Copeland method (Sayadinia & Beheshtinia, 2021). For the complexity problem of hiding individual property, rankings were made using Z-numbers together with the ELECTRE-III method and the results were combined with the weighted Copeland method (Hu & Lin, 2022). For ten battery electric vehicles, rankings were made with different MCDM methods and the results were combined with the Copeland and Borda methods (Ecer, 2021). SAW, TOPSIS and ELECTRE techniques were used using the data collected with the SERVQUAL scale from all patients admitted to a clinic of a public hospital in Tehran, and the results of the different techniques were combined using the Copeland Method (Azimi & Makui, 2017).

Benchmark method, the details of which will be explained later, is an important approach in choosing a suitable MCDM method. But finding a reference point in this approach is a challenge. In the literature, there are studies carried out with benchmark-based approaches. In the study in which a benchmark analysis was performed with Eight MCDM methods (Simple Additive Weighting, Multiplicative Exponential Weighting, TOPSIS, ELECTRE, and four AHP variants), 4800 decision problems and 38,400 solutions were performed with the data obtained by simulation, and the results were given with Spearman's rank correlation coefficient (Zanakis et al., 1998). Chang et al (2013) used 18 fuzzy combinations of two group rating mean methods (arithmetic and geometric mean), three multi-criteria methods (Simple Additive Weighting, Weighted Product, and TOPSIS), and three defuzzification methods (Center-of-area, graded mean integration, and metric distance). They were proposed novel method and the results were compared with the combination of the individual decision maker and the fuzzy method. In the study of Hajkowicz and Higgins (Hajkowicz & Higgins, 2006), the rankings were compared using five methods (Simple Additive Weighting, Range of Value Method, PROMETHEE II, Evamix, and Compromise programming) and Spearman and Kendall correlations were used to compare the rankings. In the study in which five different MCDM methods were applied to three decision making problems (ELECTRE, AHP, UTA, MAPPAC, and ORESTE), expert judgment was used to compare the results (Śak, 2005). The similarity of the results was investigated by performing a simulation study involving various weighting methods and various normalization techniques of the MCDM model input data (Sałabun et al., 2020).

When the literature is reviewed, it has been shown that stronger models and results were obtained when both subjective and objective criterion weighting methods

were used together. In addition, the results were obtained by combining the different ranking results with the Copeland and Borda methods. Based on this information in the literature, a new way was proposed by using this information in this study. Also, different criteria weighting methods and different MCDM methods were evaluated together, and a new way was proposed by applying Copeland method twice. The analysis of rank similarity obtained using different MCDM methods was compared with the actual ranking of universities. At the same time, the similarity of the rankings was calculated with the Spearman rank correlation coefficient.

This study investigates how to obtain a common result by using different criteria weighting and alternative ranking methods. A new way is proposed in which different methods can be used together. Using this proposed way, the results were tested with the satisfaction ranking of foundation universities in Türkiye.

1.1. MCDM Methods Selection and Benchmarking Problem

There are many studies in the literature for the problem of choosing the right multi-criteria method for a particular decision problem. These studies can be classified as benchmark analysis, multi-criteria analysis, informal and formal configuration of the problem or decision-making situation.

When a method based on multi-criteria analysis is preferred, criteria should be selected first. After determining the criteria, an MCDM method should be chosen to select the appropriate method. So, there is a possibility of a loop. Inasmuch as the problem is to choose a suitable MCDM method, the same point can be reached again. However, studies using this approach are seen in the literature (Al-Shemmeri et al., 1997; Gershon & Duckstein, 1983).

The informal approach to method selection involves choosing a method for a particular decision problem based on the heuristic analysis done by the analyst/decision maker. This analysis is usually based on the author's thoughts and an unstructured explanation of the decision problem and the characteristics of certain methods. The methodical approach is similar to the semi-formal approach, but the characteristics of the individual MCDM methods are somewhat structured (e.g. the table describing the methods). There are studies in the literature in which these methods are used (Adil et al., 2014; Moghaddam et al., 2011)a practical method which adheres to legal requirements is important. The research that is the base for this paper aimed at identifying a suitable Multi-Criteria Decision Analysis (MCDA.

In the formal approach to the selection of the MCDM method, the description of the individual methods is fully structured (for example, taxonomy or a table with the characteristics of individual MCDM methods). The decision problem and the selection method of one or a group of MCDM methods that are considered for evaluation are formally defined as artificial neural networks or decision trees. These are frameworks that enable the selection of an MCDM method based on the formal definition of methods and decision problem (Hwang & Yoon, 1981; Moffett & Sarkar, 2006)at the next stage, Regime is the most appropriate method to refine the NDS. If the alternatives can also be given quantitative values by the criteria, Goal Programming will prove useful in many contexts. If both the alternatives and the criteria can be quantitatively evaluated, and the criteria are independent of each other but may be compounded, then multi-attribute value theory (MAVT.

The benchmarking approach is particularly important. This approach focuses on comparing results obtained with individual methods. The main problem of applying this approach is to find a reference point to compare the results of the examined multi-criteria methods. Some authors use the expert ranking as a reference point, while others compare the results with the performance of a chosen method or examine the concordance of individual rankings obtained different MCDM methods (Chang et al., 2013; Hajkowicz & Higgins, 2006; Śak, 2005)

1.2. Copeland method

In the Copeland method, the difference of the number of times an alternative wins and loses to other alternatives is taken and the alternatives are ranked. In the Copeland method, first, a matrix with alternatives in rows and columns is used to make pairwise comparisons for each method. During the comparison, if the alternative is ahead of the other alternative, it receives a score of 1 or 0. These scores are then summed up. A comparison is made again using these scores. Thus, victory and defeat scores are calculated. By adding the victory and defeat scores, the final ranking result is obtained. Thus, multiple ranking results are combined into a single result.

1.3. Research question and purpose of the research

There are different approaches to choosing an appropriate method for MCDA. A researcher can choose Benchmark method, multi-criteria analysis and informal and/or formal structuring to find the appropriate method. There is no clear information on which of these approaches is better. Therefore, the research problem addressed in this study is how to achieve a common result by using different criteria weighting and alternative ranking methods. Because a researcher may want to use both expert opinion-based and data-based criteria weighting methods. In this case, this problem can be solved by using a two-layer architecture to combine the results obtained from different methods. As a result, this study was carried out to create a final model by combining the results of different criteria weighting and alternative ranking methods with a two-layer architecture and thus to propose a new way that can be used to select an appropriate method.

2. Method

In the study, TOPSIS, VIKOR, AHP and PROMETHEE were used as MCDM methods and AHP, SWARA, CRITIC and ENTROPY as criteria weighting methods.

The reason for using these methods is the breadth of these methods that they bring to the analyzes carried out on MCDM in WoS and Scopus databases between 1977 and 2022 (Basílio et al., 2022). In this study, a new way has been developed for MCDM problems. With the way proposed in this study, different MCDM methods and criteria weighting methods can be embedded in the model. It can work independently of the number of ranking methods and criteria weighting methods to be used.

The explanation of the developed model is given in Figure 1. In total, 18 models were developed. It has been tested that the most recently created final models will achieve the most accurate ranking and whether they can be used as a benchmark model.

For the model used in this study, the Copeland aggregation method was used twice. For example, weights were determined by SWARA method. Then, using these weights, ranking was performed with TOPSIS, VIKOR and PROMETHEE methods. For SWARA, we have three different rankings. Copeland method is used to combine these three different rankings. There is now a single ranking result for SWARA. But when the same process is done for AHP, CRITIC and ENTROPY, we have four different rankings. Finally, these rankings can be combined again with Copeland to obtain the final model.

As can be seen in Figure 1, the Copeland method was applied twice to combine different criteria weighting and ranking methods. This is because when a criterion weighting method is used with more than one ranking method, different rankings are obtained. In the first layer, these are combined with Copeland. When this process is done for each criterion weighting, we have different rankings again. In the second layer, these rankings are combined to obtain the final ranking.

To test the results of the developed model in the study, the satisfaction ranking of foundation universities in Turkey has been used with the TUMA-2022 dataset. This dataset has been collected through interviews conducted with 47,682 students by using the 'Student Satisfaction Scale'. The top 20 most satisfied foundation universities have been analyzed within the extent of the study. The dataset is shown in Table 1.

For Foundation Universities, summary tables have been coded for clarity, and they are indicated in Table 2.

Additionally, for the Foundation Universities's criteria, summary tables have been coded for clarity, and they are shown in Table 3.

3. Application

According to the information obtained from Foundation Universities, Analytic Hierarchy Process (AHP), Stepwise Weight Assessment Ratio Analysis (SWARA), Criteria Importance Through Intercriteria Correlation

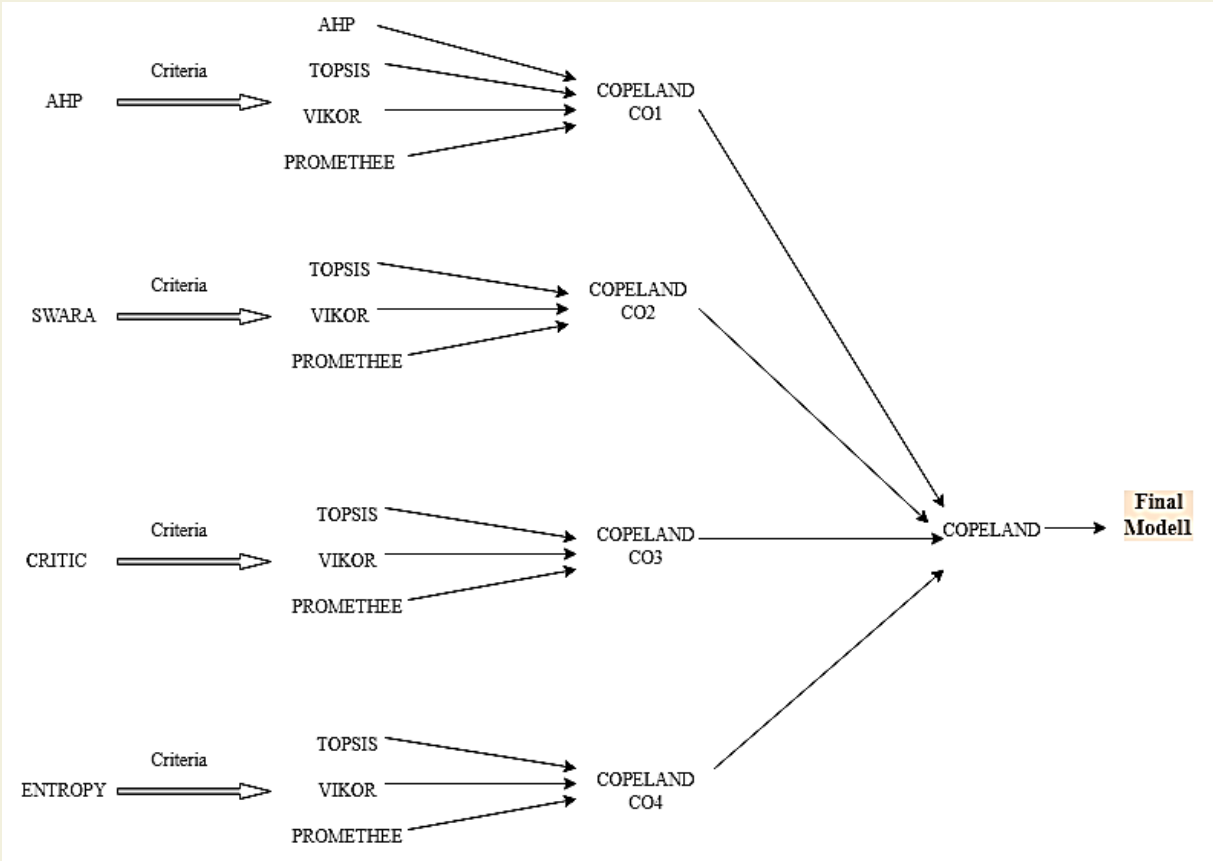

Figure 1. Final Model

Table 1. Foundation Universities

S.N	University	Satisfaction of the Learning Experience	The Campus and the Saturation of Life	Academic Support and Interest	Management and Operation of the Inst.	Richness of Learning Opportunities and Resources	Personal Development and Career Support
		Point	Point	Point	Point	Point	Point
1	Ihsan Dogramaci Bilkent University	87	86	88	58	91	89
2	Sabanci University	87	86	85	82	89	90
3	Ozyegin University	82	87	84	84	88	89
4	MEF University	86	82	85	88	85	86
5	Piri Reis University	85	84	86	87	84	85
6	Bezmialem Vakif University	87	77	86	87	85	86
7	Acibadem Mehmet Ali Aydinlar University	83	84	85	81	85	87
8	Koc University	83	84	82	82	89	85
9	Hasan Kolyoncu University	80	86	83	86	83	81
10	Yasar University	83	82	84	84	81	84
11	Izmir University of Economics	84	83	83	77	81	85
12	TED University	80	78	83	84	83	80
13	Maltepe University	79	81	77	82	82	78
14	Istanbul Bilgi University	76	81	83	64	86	83
15	Sanko University	84	63	86	86	69	84
16	Kadir Has University	74	81	77	68	79	78
17	Ibn Haldun University	72	82	76	67	82	77
18	Beykoz University	75	64	82	85	73	73
19	Fatih Sultan Mehmet Vakif University	75	68	78	82	73	75
20	Altinbas University	78	75	74	80	71	72

Table 2. Foundation Universities And Codes

Rank	KOD	University	Rank	CODE	University
1	V1	Acibadem Mehmet Ali Aydınlar University	11	V11	Kadir Has University
2	V2	Altinbas University	12	V12	Koc University
3	V3	Beykoz University	13	V13	Maltepe University
4	V4	Bezmialem Vakif University	14	V14	MEF University
5	V5	Fatih Sultan Mehmet Vakif University	15	V15	Ozyegin University
6	V6	Hasan Kolyoncu University	16	V16	Piri Reis University
7	V7	Ibn Haldun University	17	V17	Sabanci University
8	V8	İhsan Dogramacı Bilkent University	18	V18	Sanko University
9	V9	Istanbul Bilgi University	19	V19	TED University
10	V10	Izmir University of Economics	20	V20	Yasar University

(CRITIC), and ENTROPY methods have been used as weighting methods. As for ranking methods, AHP, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), and Preference Ranking Organization METHod for Enrichment Evaluations (PROMETHEE) methods have been integrated and utilized. The AHP method has been used for both weighting and ranking purposes.

Table 3. Codes of Criteria

Criteria	Code
Satisfaction of the Learning Experience	KR1
The Campus and the Saturation of Life	KR2
Academic Support and Interest	KR3
Satisfaction with the Management and Operation of the Institution	KR4
Richness of Learning Opportunities and Resources	KR5
Personal Development and Career Support	KR6

3.1. Weighting and Ranking According to the AHP Method

Pairwise comparisons were made by 5 experts for the 6 criteria of Foundation Universities' data. The decision matrix is given in Table 4.

Table 4. Decision Matrix According to the AHP Method

Criteria	KR1	KR2	KR3	KR4	KR5	KR6
KR1	1,00	1,81	0,44	0,94	0,20	0,26
KR2	0,55	1,00	0,35	1,57	0,43	0,27
KR3	2,27	2,89	1,00	3,47	1,68	1,12
KR4	1,06	0,64	0,29	1,00	0,52	0,79
KR5	4,92	2,32	0,60	1,93	1,00	0,33
KR6	3,90	3,68	0,89	1,26	3,06	1,00

* Consistency 0,07

The weight values of the criteria according to the AHP method are given in Table 5.

Table 5. Weight Values and Rankings of Criteria According to AHP Method

Criteria	Weight Values	Criterion Priorities
KR1	0,0889	6
KR2	0,0846	5
KR3	0,2603	2
KR4	0,0989	4
KR5	0,1894	3
KR6	0,2778	1

After calculating the weight values of alternatives according to the criteria, the relative importance weights of alternatives were determined these values with the weights of the main criteria by multiplying and summing. Subsequently, the ranking of Foundation Universities was done according to the AHP method.

Table 6. Ranking of Foundation Universities by AHP Method

S.N	1	2	3	4	5	6	7	8	9	10
Rank	V17	V15	V8	V14	V4	V16	V1	V12	V20	V6
S.N	11	12	13	14	15	16	17	18	19	20
Rank	V10	V19	V9	V18	V13	V11	V7	V3	V5	V2

3.2. Ranking by AHP- TOPSIS Method

The data of Foundation Universities were weighted by the AHP method, and then these weight values were used in the TOPSIS method to rank the Foundation Universities.

3.3. Ranking by AHP-VIKOR Method

Foundation Universities were weighted with the AHP Method and ranked by the VIKOR Method. According to the VIKOR Method;

Condition 1: Q(P2)-Q(P1)≥D(Q), and D(Q) = 1/(6-1)= 0,20

Q(17)-Q(8)= 1,363-1,096 = 0,267 ≥ 0,20 therefore Condition 1 is satisfied.

Condition 2: Alternative P1, which has the highest Q value, should have obtained the best score in at least one of the S and R values. At Table 8, this condition has not been satisfied for the S and R values.

If at least one of these two conditions is satisfied according to the VIKOR method, Q8 and Q17 are considered as compromise solutions.

Table 7. Ranking of Foundation Universities According to AHP-TOPSIS Method

S.N	V17	V15	V14	V1	V4	V16	V12	V8	V20	V10
Rank	1	2	3	4	5	6	7	8	9	10
S.N	V6	V9	V19	V18	V13	V7	V11	V3	V5	V2
Rank	11	12	13	14	15	16	17	18	19	20

Table 8. Ranking of S, R and Q Values According to AHP-VIKOR Method

Sj	Rj	Qj
S17	R14	Q8
S8	R4	Q17
S15	R16	Q15
S4	R6	Q18
S14	R15	Q12
S16	R19	Q6
S1	R20	Q16
S12	R5	Q3
S20	R12	Q19
S10	R13	Q13
S6	R17	Q4
S19	R1	Q14
S9	R2	Q2
S18	R3	Q7
S13	R18	Q5
S11	R10	Q11
S7	R11	Q20
S3	R7	Q10
S5	R9	Q1
S2	R8	Q9

Table 9. Ranking of Foundation Universities According to AHP-VIKOR Method

S.N	V8	V17	V15	V18	V12	V6	V16	V3	V19	V13
Rank	1	2	3	4	5	6	7	8	9	10
S.N	V4	V14	V2	V7	V5	V11	V20	V10	V1	V9
Rank	11	12	13	14	15	16	17	18	19	20

3.4. Ranking By AHP-PROMETHEE Method

Foundation Universities are weighted with the AHP

Method and ranked by the PROMETHEE Method. These rankings are given in table 10.

Table 10. Ranking of Foundation Universities According to AHP-PROMETHEE Method

S.N	V17	V8	V15	V4	V14	V16	V1	V12	V20	V10
Rank	1	2	3	4	5	6	7	8	9	10
S.N	V6	V19	V9	V18	V13	V11	V7	V3	V5	V2
Rank	11	12	13	14	15	16	17	18	19	20

3.5. The AHP, TOPSIS, VIKOR, PROMETHEE methods, which were weighted with the AHP method, were combined with the Copeland method

The methods weighted and ranked by the AHP method (AHP, TOPSIS, VIKOR, PROMETHEE) have been merged into a single ranking using the Copeland method in table 11. That is, it is the ranking called CO1 in the way shown in Figure 1.

Table 11. Ranking and Combining of Foundation Universities with AHP, TOPSIS, VIKOR, PROMETHEE Methods with AHP criteria weighted

S.N	AHP	TOPSIS	VIKOR	PROMETHEE	Copeland
	Rank	Rank	Rank	Rank	Rank
1	V17	V17	V8	V17	V17
2	V15	V15	V17	V8	V8
3	V8	V14	V15	V15	V15
4	V14	V1	V18	V4	V4
5	V4	V4	V12	V14	V14
6	V16	V16	V6	V16	V16
7	V1	V12	V16	V1	V1
8	V12	V8	V3	V12	V12
9	V20	V20	V19	V20	V20
10	V6	V10	V13	V10	V6
11	V10	V6	V4	V6	V10
12	V19	V9	V14	V19	V19
13	V9	V19	V2	V9	V9
14	V18	V18	V7	V18	V18
15	V13	V13	V5	V13	V13
16	V11	V7	V11	V11	V7
17	V7	V11	V20	V7	V11
18	V3	V3	V10	V3	V3
19	V5	V5	V1	V5	V5
20	V2	V2	V9	V2	V2

3.6. Ranking By SWARA-TOPSIS

According to the SWARA method, the weight values of criteria for Foundation Universities were obtained through a survey conducted with expert opinions.

In Table 12, According to the SWARA method, the weight values of criteria are provided.

Table 12. Weight Values and Rankings of the Criteria According to the SWARA Method

Criteria	KR1	KR2	KR3	KR4	KR5	KR6
Wi	0,153	0,125	0,212	0,136	0,206	0,168
Rank	4	6	1	5	2	3

With these weight values, various alternative methods were used to rank the alternatives.

Table 13. Ranking of Foundation Universities By SWARA-TOPSIS Method

S.N	V17	V15	V14	V16	V4	V12	V1	V6	V20	V10
Rank	1	2	3	4	5	6	7	8	9	10
S.N	V19	V8	V13	V9	V18	V7	V3	V11	V5	V2
Rank	11	12	13	14	15	16	17	18	19	20

3.7. Ranking By SWARA-VIKOR

Foundation Universities were weighted with the AHP Method and ranked by the VIKOR Method. According to the VIKOR Method;

Condition 1: $Q(P2)-Q(P1)\geq D(Q)$, and $D(Q) = 1/(6-1)= 0,20$

$Q(17)-Q(8)= 1,563-1,053 = 0,510 \geq 0,20$ therefore Condition 1 is satisfied.

Condition 2: The alternative P1 with the highest Q value

Table 14. Ranking of S, R and Q Values According to AHP-VIKOR Method

Sj	Rj	Qj
S17	R14	Q8
S8	R4	Q17
S15	R16	Q18
S14	R6	Q15
S4	R15	Q16
S16	R19	Q12
S1	R20	Q14
S12	R5	Q4
S20	R12	Q13
S10	R13	Q20
S6	R17	Q6
S19	R1	Q10
S9	R2	Q7
S18	R3	Q2
S13	R18	Q3
S11	R10	Q11
S7	R11	Q5
S3	R7	Q19
S5	R9	Q1
S2	R8	Q9

should have obtained the best score in either S or R values. However, when looking at Table 14, this condition has not satisfied for S and R values.

If at least one of these two conditions is satisfied by the VIKOR method, Q8 and Q17 are compromise solutions.

Table 15. Ranking of Foundation Universities According to SWARA-VIKOR Method

S.N	V8	V17	V18	V15	V16	V12	V14	V4	V13	V20
Rank	1	2	3	4	5	6	7	8	9	10
S.N	V6	V10	V7	V2	V3	V11	V5	V19	V1	V9
Rank	11	12	13	14	15	16	17	18	19	20

3.8. Ranking By SWARA-PROMETHEE Method

Foundation Universities are weighted with the SWARA Method and ranked by the PROMETHEE Method.

Table 16. Ranking of Foundation Universities By SWARA-PROMETHEE Method

Rank	V17	V8	V15	V14	V4	V16	V1	V12	V20	V10
S.N	1	2	3	4	5	6	7	8	9	10
Rank	V6	V19	V9	V18	V13	V11	V7	V3	V5	V2
S.N	11	12	13	14	15	16	17	18	19	20

Table 17. Ranking and Combining of Foundation Universities According to TOPSIS, VIKOR, PROMETHEE Methods

No	TOPSIS	VIKOR	PROMETHEE	Copeland
	Rank	Rank	Rank	Rank
1	V17	V8	V17	V17
2	V15	V17	V8	V8
3	V14	V18	V15	V15
4	V16	V15	V14	V14
5	V4	V16	V4	V16
6	V12	V12	V16	V4
7	V1	V14	V1	V12
8	V6	V4	V12	V1
9	V20	V13	V20	V20
10	V10	V20	V10	V6
11	V19	V6	V6	V10
12	V8	V10	V19	V19
13	V13	V7	V9	V9
14	V9	V2	V18	V13
15	V18	V3	V13	V18
16	V7	V11	V11	V7
17	V3	V5	V7	V3
18	V11	V19	V3	V11
19	V5	V1	V5	V2
20	V2	V9	V2	V5

3.9. The TOPSIS, VIKOR, PROMETHEE methods, which were weighted with the SWARA method, were combined with the Copeland method.

The methods weighted by using the SWARA (Step-wise Weight Assessment Ratio Analysis) method and ranked (TOPSIS, VIKOR, PROMETHEE) have been merged into a single ranking by using the Copeland method in table 17.

3.10. Ranking by CRITIC-TOPSIS

According to the CRITIC Method, the weight values of the Foundation Universities criteria were obtained.

The weight values of the criteria have been provided with the CRITIC (CRiteria Importance Through Intercriteria Correlation) method in table 18.

Table 18. Weight Values and Rankings of the criteria by the CRITIC Method

Criteria	K1	K2	K3	K4	K5	K6
Wj	0,095	0,207	0,087	0,375	0,143	0,093
Rank	4	2	6	1	3	5

With these weight values, alternative rankings have been performed by using various ranking methods.

Table 19. Ranking of Foundation Universities by CRITIC-TOPSIS Method

Rank	V16	V14	V15	V6	V4	V17	V20	V12	V19	V1
S.N	1	2	3	4	5	6	7	8	9	10
Rank	V13	V10	V18	V3	V2	V5	V11	V7	V9	V8
S.N	11	12	13	14	15	16	17	18	19	20

3.11. Ranking by CRITIC-VIKOR

Foundation Universities were weighted with the AHP Method and ranked by the VIKOR Method. According to the VIKOR Method;

Condition 1: $Q(P2)-Q(P1) \geq D(Q)$, and $D(Q) = 1/(6-1) = 0,20$

$Q(17)-Q(8) = 1,268-1,018 = 0,250 \geq 0,20$ which is greater than or equal to 0.20, thus satisfying condition 1.

Condition 2: To have the highest Q value, alternative P1 must have achieved the highest score in at least one of the S and R values. However, in Table 20, it can be observed that this condition is not satisfied for both S and R values.

According to the VIKOR method, if at least one of these two conditions is satisfied, Q8 and Q17 are considered as compromise solutions.

Table 20. Ranking of S, R and Q Values By the CRITIC-VIKOR Method

Sj	Rj	Qj
S17	R14	Q8
S14	R4	Q17
S15	R16	Q9
S16	R6	Q4
S4	R18	Q18
S12	R3	Q10
S6	R15	Q7
S1	R19	Q15
S20	R20	Q11
S19	R5	Q1
S10	R12	Q14
S13	R13	Q12
S8	R17	Q3
S18	R1	Q16
S9	R2	Q6
S3	R10	Q5
S2	R11	Q20
S5	R7	Q19
S11	R9	Q2
S7	R8	Q13

Table 21. Ranking of Foundation Universities By CRITIC-VIKOR Method

Rank	V8	V17	V9	V4	V18	V10	V7	V15	V11	V1
S.N	1	2	3	4	5	6	7	8	9	10
Rank	V14	V12	V3	V16	V6	V5	V20	V19	V2	V13
S.N	11	12	13	14	15	16	17	18	19	20

3.12. Ranking By CRITIC-PROMETHEE Method

The Foundation Universities have been weighted with the CRITIC method and ranked by the PROMETHEE method.

Table 22. Ranking of Foundation Universities By CRITIC-PROMETHEE Method

Rank	V17	V14	V15	V16	V4	V12	V6	V1	V20	V19
S.N	1	2	3	4	5	6	7	8	9	10
Rank	V10	V13	V8	V18	V9	V3	V2	V5	V11	V7
S.N	11	12	13	14	15	16	17	18	19	20

3.13. The TOPSIS, VIKOR, PROMETHEE methods, which were weighted with the CRITIC method, were combined with the Copeland method.

The methods weighted with the CRITIC method and ranked (TOPSIS, VIKOR, PROMETHEE) have been merged into a single ranking with the Copeland method.

Table 23. Ranking and Combining of Foundation Universities According to AHP, TOPSIS, VIKOR, PROMETHEE Methods

No	TOPSIS	VIKOR	PROMETHEE	Copeland
	Rank	Rank	Rank	Rank
1	V16	V16	V8	V17
2	V14	V14	V17	V14
3	V15	V15	V9	V15
4	V6	V6	V4	V16
5	V4	V4	V18	V4
6	V17	V17	V10	V12
7	V20	V20	V7	V6
8	V12	V12	V15	V1
9	V19	V19	V11	V20
10	V1	V1	V1	V19
11	V13	V13	V14	V10
12	V10	V10	V12	V13
13	V18	V18	V3	V8
14	V3	V3	V16	V18
15	V2	V2	V6	V9
16	V5	V5	V5	V3
17	V11	V11	V20	V2
18	V7	V7	V19	V5
19	V9	V9	V2	V11
20	V8	V8	V13	V7

3.14. Ranking by ENTROPY-TOPSIS

According to the ENTRPOY Method, the weight values of the Foundation Universities criteria were obtained.

The weight values of the criteria are given according to the ENTROPY method in table 24.

Table 24. Weight Values and Rankings of the Criteria by the ENTROPY Method

Criteria	KR1	KR2	KR3	KR4	KR5	KR6
Wj	0,16618	0,16773	0,1658082	0,17005	0,16342	0,16681
Rank	4	2	5	1	6	3

With these weight values in table 24, alternative rankings have been performed using various ranking methods.

Table 25. Ranking of Foundation Universities by ENTROPY-TOPSIS Method

Rank	V17	V15	V14	V16	V12	V1	V4	V6	V20	V10
S.N	1	2	3	4	5	6	7	8	9	10
Rank	V19	V13	V8	V18	V9	V3	V2	V7	V5	V11
S.N	11	12	13	14	15	16	17	18	19	20

3.15. Ranking by ENTROPY-VIKOR

Foundation Universities are weighted with the ENTROPY Method and ranked by the VIKOR Method. According to the VIKOR Method;

Condition 1: Q(P2)-Q(P1)≥D(Q), and D(Q) = 1/(6-1)= 0,20

Q(17)-Q(8)= 1,786-1,048 = 0,738 ≥ 0,20 which is greater than or equal to 0.20, thus satisfying condition 1.

Condition 2: To have the highest Q value, alternative P1 must have achieved the highest score in at least one of the S and R values. However, in Table 26, it can be observed that this condition is not satisfied for both S and R values.

By the VIKOR method, if at least one of these two conditions is satisfied, Q8 and Q17 are considered as compromise solutions.

Table 26. Ranking of S, R and Q Values By the CRITIC-VIKOR Method

Sj	Rj	Qj
S17	R14	Q8
S15	R4	Q17
S14	R16	Q4
S16	R6	Q15
S4	R15	Q18
S8	R19	Q16
S1	R20	Q14
S12	R12	Q6
S20	R13	Q12
S6	R17	Q9
S10	R5	Q13
S19	R1	Q3
S18	R2	Q7
S9	R10	Q20
S13	R3	Q19
S11	R18	Q2
S7	R11	Q11
S3	R7	Q10
S5	R9	Q5
S2	R8	Q1

Table 27. Ranking of Foundation Universities by ENTROPY-VIKOR Method

Rank	V8	V17	V4	V15	V18	V16	V14	V6	V12	V9
S.N	1	2	3	4	5	6	7	8	9	10
Rank	V13	V3	V7	V20	V19	V20	V11	V10	V5	V1
S.N	11	12	13	14	15	16	17	18	19	20

3.16. Ranking By ENTROPY-PROMETHEE

Foundation Universities are weighted with the ENTROPY Method and ranked by the PROMETHEE Method.

Table 28. Ranking of Foundation Universities By ENTROPY-PROMETHEE Method

Rank	V17	V15	V14	V16	V4	V8	V1	V12	V20	V6
S.N	1	2	3	4	5	6	7	8	9	10
Rank	V10	V19	V18	V9	V13	V11	V7	V3	V5	V2
S.N	11	12	13	14	15	16	17	18	19	20

3.17. The TOPSIS, VIKOR, PROMETHEE methods, which were weighted with the ENTROPY method, were combined with the Copeland method.

The methods weighted with the ENTROPY method and ranked (TOPSIS, VIKOR, PROMETHEE) have been merged into a single ranking by using the Copeland method.

Table 29. Ranking and Combining of Foundation Universities By AHP, TOPSIS, VIKOR, PROMETHEE Methods

No	TOPSIS	VIKOR	PROMETHEE	Copeland
	Rank	Rank	Rank	Rank
1	V17	V8	V17	V17
2	V15	V17	V15	V15
3	V14	V4	V14	V14
4	V16	V15	V16	V16
5	V12	V18	V4	V4
6	V1	V16	V8	V8
7	V4	V14	V1	V12
8	V6	V6	V12	V1
9	V20	V12	V20	V6
10	V10	V9	V6	V20
11	V19	V13	V10	V10
12	V13	V3	V19	V19
13	V8	V7	V18	V18
14	V18	V20	V9	V9
15	V9	V19	V13	V13
16	V3	V2	V11	V3
17	V2	V11	V7	V7
18	V7	V10	V3	V2
19	V5	V5	V5	V11
20	V11	V1	V2	V5

3.18. The rankings obtained by various weighting methods and merged using the Copeland method are further combined using the Copeland method once again

The rankings of alternatives were determined by using the AHP, SWARA, CRITIC, ENTROPY methods, and the average of these four methods, along with the TOPSIS, VIKOR, and PROMETHEE methods. Subsequently, the rankings of alternatives obtained from weighting methods were merged by using the Copeland method to create a unified ranking. In total, 5 Copeland methods

were employed to generate the consolidated ranking of alternatives. Next, the rankings from these 4 methods were further combined using the Copeland method to create Model 1, and the average of these four methods was used to create Model 2.

Table 30. Final model named Two-layer Copeland

No	CO1	CO2	CO3	CO4	FINAL MODEL
	Rank	Rank	Rank	Rank	Rank
1	V17	V17	V17	V17	V17
2	V8	V8	V14	V15	V15
3	V15	V15	V15	V14	V14
4	V4	V14	V16	V16	V16
5	V14	V16	V4	V4	V4
6	V16	V4	V12	V8	V8
7	V1	V12	V6	V12	V12
8	V12	V1	V1	V1	V1
9	V20	V20	V20	V6	V20
10	V6	V6	V19	V20	V6
11	V10	V10	V10	V10	V10
12	V19	V19	V13	V19	V19
13	V9	V9	V8	V18	V9
14	V18	V13	V18	V9	V13
15	V13	V18	V9	V13	V18
16	V7	V7	V3	V3	V3
17	V11	V3	V2	V7	V7
18	V3	V11	V5	V2	V11
19	V5	V2	V11	V11	V2
20	V2	V5	V7	V5	V5

The relationship between the reference ranking and the rankings obtained from the proposed model is shown in Figure 2.

To demonstrate the relationship between the rankings of universities based on the generated Final Model and their actual rankings statistically, Spearman Rank Correlation values have been calculated and are given in Table 31.

4. Discussion

In this study, a new hybrid model was proposed by using different MCDM methods together. The proposed model was used for the ranking of Turkish foundation universities.

When the research findings were examined, it was determined that the final model showed a better correlation with the reference model. The model resulted in 0.965 correlation, which is very close to the real result. In addition, since the Copeland method was used twice in the model, it can be said that it gave better results than the other models. Therefore, sequential use of the Copeland method may have increased the correlation.

During the creation of the final model, intermediate models Copeland1 (CO1), Copeland2 (CO2), Copeland3 (CO3) and Copeland4 (CO4) were also established. When the correlations of these intermediate models with the reference model were examined, it was determined that the models named CO1 and CO2 gave slightly better results (0.986 and 0.988 correlation) than the final model (0.965 correlation), but the models named CO3 and CO4

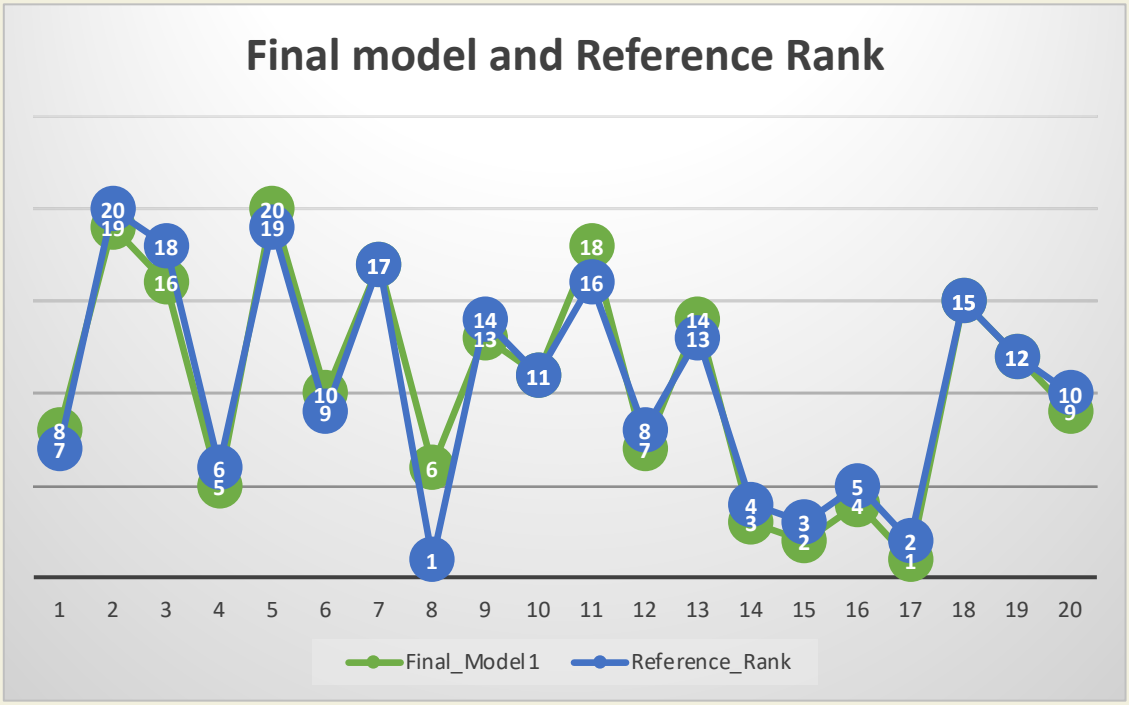

Figure 2. The relationship between the reference ranking and the rankings obtained from the proposed model

Table 31. Correlation Between Various Models

		Co1	Co2	Co3	Co4	Final m.	AHP-AHP	AHP-TOPSIS	AHP-VIKOR	AHP-PROM.
Reference Rank	r	,986	,988	,850	,956	,965	,988	,938	,472	,985
	Sig.	,000	,000	,000	,000	,000	,000	,000	,036	,000
	N	20	20	20	20	20	20	20	20	20
		SWA-RA-TOPSIS	SWARA-VI-KOR	SWA-RA-PROM.	CRITIC-TOP-SIS	CRITIC-VI-KOR	ENTR.-TOP-SIS	ENTROP-Y-VIKOR	ENTR.-PROM.	
Reference Rank	r	,895	,651	,988	,597	,411	,853	,659	,970	
	Sig.	,000	,002	,000	,005	,072	,000	,002	,000	
	N	20	20	20	20	20	20	20	20	

(0.85 and 0.956 correlation) were worse. These results are an important indicator that different criteria weighting methods give different results when used with different ranking algorithms (Cinelli et al., 2020; Roy, 1996). Therefore, using modules that give such different results together will ensure that the results are more reliable. Therefore, it will be important to combine these models with the Copeland method and combine the resulting models with Copeland again to obtain reliable results. Because the methods were used together and more successful results were given, the model was named Two-layer Copeland and benefited from the power of all models.

The fact that the proposed model uses subjective methods such as AHP and SWARA as criterion weighting, as well as objective methods such as CRITIC and ENTROPY. AHP and SWARA criterion weighting may have provided more successful results with 0.986 and 0.988 correlation. According to Tajik et al.(Tajik et al., 2023) They stated that using both objective and subjective criteria weighting methods together is a factor that increases success. Therefore, the Two-layer Copeland proposed in this study can be used to obtain reliable results. However, if the AHP method is used both as a criterion weighting and ranking method, it is an important result that it correlates with the reference ranking with a high ratio of 0.98. In the SWARA method, on the other hand, there was a decrease in the correlation values. These findings show that subjective criteria weighting methods can produce different results, so it should not be adhered to a single criterion weighting method (Cinelli et al., 2020; Roy, 1996).

An important result in terms of study results is related to the PROMETHEE method. It has been determined that different criterion weighting methods give better results when combined with the PROMETHEE method (all correlation values are 0.97 and above). This shows that the PROMETHEE method can be used as a good ranking method independent of criterion weighting methods. This situation is similar with the studies using the PROMETHEE method and achieving successful results in the literature. The success here is that the results are close to the real rankings (Ishizaka & Resce, 2021; Kilic et al., 2015; Singh et al., 2021). However, it was observed that there was a decrease in the correlation values in the CRITIC-PROMETHEE pair. This indicates that caution should be exercised when using PROMETHEE with CRITIC (Animah & Shafiee, 2021; Chisale et al., 2023; Khan & Purohit, 2022).

Since the actual order of the dataset used in this study is known, it was possible to compare the results of the MCDM methods and the proposed models. However, in the real world, MCDM methods are applied on alternatives whose real order is unknown. Therefore, it is not possible to know which method gives the best results. Therefore, it is not possible to make a benchmark test. In this study, the results of all models are evaluated with the model named Two-layer Copeland, and it has been shown that it gives results close to the methods that give the best results. Therefore, it is thought that this proposed model can be used for a benchmark test.

5. Conclusion

This study investigated how different criteria weighting and ranking methods can be used together. The relationship between the final ranking and the actual ranking is also analyzed. In this study, a two-layer structure was used. The first layer contains different criteria weighting methods and the second layer contains different ranking methods. For this purpose, a way including 4 different criteria weighting and 4 different ranking methods is proposed. By using the proposed way, the ranking of foundation universities in Türkiye was realized.

High correlation (0.986, 0.988 ,0.850 ,0.956) was found between the results obtained in the final model and the results obtained in the first layer (Co1, Co2, Co3, Co4). The correlation coefficient between the reference model and the final model was significant (r = 0.965). These results show that the proposed way in this study gives results very close to the actual ranking. When the criteria are weighted with the CRITIC method and used with different ranking methods, the correlation values were quite low. Similarly, the correlation between the results of combining the different rankings obtained with the CRITIC weight values (CO3) and the final model results also decreased (0.85). However, combining the ranking resulted in an increase in the correlation of the CRITIC method with the actual ranking from 0.5 to 0.85. Therefore, it can be suggested that researchers should be more

careful when using the CRITIC weighting method in university ranking.

In addition, as a result of the study, the criterion weighting results obtained by AHP and SWARA methods gave the closest results to the actual ranking, but the correlation values are low in AHP-VIKOR and SWARA-VIKOR methods. However, as in the CRITIC method, the correlation value with the actual ranking increased when the rankings were combined.

Another important result obtained is that PROMETHEE is highly correlated with the actual ranking regardless of the criteria weighting method. This result shows that the PROMETHEE method gives high success in alternative ranking without being affected by the criteria weights.

When all methods were combined in the second layer, a high correlation with the actual ranking was obtained. The very low correlation of some methods (AHP-VIKOR, CRITIC-VIKOR, etc.) did not have much effect on the result with the overall combination. This shows us that if all methods are used together and the results are combined, the negative effects of some methods can be eliminated. It also shows that it can be used as a benchmark for MCDM methods.

These correlation results showed that the hybrid models proposed in this study can give very reliable results for final decision making in MCDM problems. It has been shown that the Two-layer Copeland can be used in MCDM problems, especially since it is not known exactly which method or methods to use. In particular, the Two-layer Copeland, brings together many methods and takes advantage of all the methods. It has been shown that such a model can also be used as a benchmark in MCDM problems.

In future studies, the method proposed in this study can be tested on different datasets and the results of the model can be examined with different sensitivity analyses (Demir & Arslan, 2022).

References

Adil, M., Nunes, M. B., & Peng, G. C. (2014). Identifying operational requirements to select suitable decision models for a public sector e-procurement decision support system. *Journal of Information Systems and Technology Management*, *11*(2), 211–228. https://doi.org/10.4301/10.4301

Al-Shemmeri, T., Al-Kloub, B., & Pearman, A. (1997). Model choice in multicriteria decision aid. *European Journal of Operational Research*, *97*(3), 550–560. https://doi.org/10.1016/S0377-2217(96)00277-9

Animah, I., & Shafiee, M. (2021). Maintenance strategy selection for critical shipboard machinery systems using a hybrid AHP-PROMETHEE and cost benefit analysis: a case study. *Journal of Marine Engineering \& Technology*, *20*(5), 312–323.

Azimi, S. A. Z., & Makui, A. (2017). Prioritizing the Components Affecting Patient's Satisfaction with Healthcare Services using Multiple Attribute Decision Making Technique. *Industrial Engineering and Management Systems*, *16*(4), 479–485. https://doi.org/10.7232/iems.2017.16.4.479

Baczkiewicz, A., Kizielewicz, B., Shekhovtsov, A., Watróbski, J., & Sałabun, W. (2021). Methodical aspects of mcdm based e-commerce recommender system. *Journal of Theoretical and Applied Electronic Commerce Research*, *16*(6), 2192–2229. https://doi.org/10.3390/JTAER16060122

Basílio, M. P., Pereira, V., Costa, H. G., Santos, M., & Ghosh, A. (2022). A Systematic Review of the Applications of Multi-Criteria Decision Aid Methods (1977–2022). *Electronics 2022, Vol. 11, Page 1720*, *11*(11), 1720. https://doi.org/10.3390/ELECTRONICS11111720

Beheshtinia, M. A., & Omidi, S. (2017). A hybrid MCDM approach for performance evaluation in the banking industry. *Kybernetes*, *46*(8), 1386–1407. https://doi.org/10.1108/K-03-2017-0105

Biswas, S., Bandyopadhyay, G., & Mukhopadhyaya, J. N. (2022). A multi-criteria based analytic framework for exploring the impact of Covid-19 on firm performance in emerging market. *Decision Analytics Journal*, *5*. https://doi.org/10.1016/J.DAJOUR.2022.100143

Biswas, S., Bandyopadhyay, G., Pamucar, D., & Joshi, N. (2022). A Multi-criteria Based Stock Selection Framework In Emerging Market. *Operational Research in Engineering Sciences: Theory and Applications*, *5*(3), 153–193. https://doi.org/10.31181/ORESTA161122121B

Chang, Y. H., Yeh, C. H., & Chang, Y. W. (2013). A new method selection approach for fuzzy group multicriteria decision making. *Applied Soft Computing*, *13*(4), 2179–2187. https://doi.org/10.1016/J.ASOC.2012.12.009

Chisale, S. W., Eliya, S., & Taulo, J. (2023). Optimization and design of hybrid power system using HOMER pro and integrated CRITIC-PROMETHEE II approaches. *Green Technologies and Sustainability*, *1*, 100005.

Cinelli, M., Kadziński, M., Gonzalez, M., & Słowiński, R. (2020). How to support the application of multiple criteria decision analysis? Let us start with a comprehensive taxonomy. *Omega*, *96*, 102261. https://doi.org/10.1016/J.OMEGA.2020.102261

Demir, G., & Arslan, R. (2022). Sensitivity Analysis in Multi-Criterion Decision-Making Problems. *Ankara Hacı Bayram Veli Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, *24*(3), 1025–1056. https://doi.org/10.26745/ahbvuibfd.1103531

Ecer, F. (2021). A consolidated MCDM framework for performance assessment of battery electric vehicles based on ranking strategies. *RENEWABLE & SUSTAINABLE ENERGY REVIEWS*, *143*. https://doi.org/10.1016/j.rser.2021.110916

Gershon, M., & Duckstein, L. (1983). *An Algorithm for Choosing of a Multiobjective Technique BT - Essays and Surveys on Multiple Criteria Decision Making* (P. Hansen (ed.); pp. 53–62). Springer Berlin Heidelberg.

Greco, S., Figueira, J., & Ehrgott, M. (2005). *Multiple criteria decision analysis*. Springer.

Guitouni, A., & Martel, J. M. (1998). Tentative guidelines to help choosing an appropriate MCDA method. *European Journal of Operational Research*, *109*(2), 501–521. https://doi.org/10.1016/S0377-2217(98)00073-3

Hajkowicz, S., & Higgins, A. (2006). *A comparison of multiple criteria analysis techniques for water resource management*. https://doi.

org/10.1016/j.ejor.2006.10.045

Hu, Z. J., & Lin, J. (2022). An integrated multicriteria group decision making methodology for property concealment risk assessment under Z-number environment. *EXPERT SYSTEMS WITH APPLICATIONS*, *205*. https://doi.org/10.1016/j.eswa.2022.117369

Hwang, C.-L., & Yoon, K. (1981). *Methods for Multiple Attribute Decision Making BT - Multiple Attribute Decision Making: Methods and Applications A State-of-the-Art Survey* (C.-L. Hwang & K. Yoon (eds.); pp. 58–191). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-48318-9_3

Ishizaka, A., & Resce, G. (2021). Best-Worst PROMETHEE method for evaluating school performance in the OECD's PISA project. *Socio-Economic Planning Sciences*, *73*, 100799.

Khan, S., & Purohit, L. (2022). An Integrated Methodology of Ranking Based on PROMETHEE-CRITIC and TOPSIS-CRITIC In Web Service Domain. *2022 IEEE 11th International Conference on Communication Systems and Network Technologies (CSNT)*, 335–340.

Kilic, H. S., Zaim, S., & Delen, D. (2015). Selecting "The Best" ERP system for SMEs using a combination of ANP and PROMETHEE methods. *Expert Systems with Applications*, *42*(5), 2343–2352.

Moffett, A., & Sarkar, S. (2006). Incorporating multiple criteria into the design of conservation area networks: a minireview with recommendations. *Diversity and Distributions*, *12*(2), 125–137. https://doi.org/10.1111/J.1366-9516.2005.00202.X

Moghaddam, N. B., Nasiri, M., & Mousavi, S. M. (2011). An appropriate multiple criteria decision making method for solving electricity planning problems, addressing sustainability issue. *International Journal of Environmental Science & Technology*, *8*(3), 605–620. https://doi.org/10.1007/BF03326246

Mohebali, S., Maghsoudy, S., & Doulati Ardejani, F. (2020). Coupled multi-criteria decision-making method: A new approach for environmental impact assessment of industrial companies. *Environmental Progress and Sustainable Energy*, *39*(6). https://doi.org/10.1002/EP.13523

Nasiri, M., Moghaddam, H. K., & Hamidi, M. (2021). Development of Multi-Criteria Decision Making Methods for Reduction of Seawater Intrusion in Coastal Aquifers Using SEAWAT Code. *Journal of Contaminant Hydrology*, *242*. https://doi.org/10.1016/J.JCONHYD.2021.103848

Roy, B. (1996). *Multicriteria Methodology for Decision Aiding*. *12*. https://doi.org/10.1007/978-1-4757-2500-1

Şahin, M. (2021). Location selection by multi-criteria decision-making methods based on objective and subjective weightings. *Knowledge and Information Systems*, *63*(8), 1991–2021. https://doi.org/10.1007/S10115-021-01588-Y

Śak, J. (2005). The Comparison Of Multiobjective Ranking Methods Applied To Solve The Mass Transit Systems' Decision Problems. *In Proceedings of the 10th Jubilee Meeting of the EURO Working Group on Transportation*, 13–16.

Sałabun, W., Watróbski, J., & Shekhovtsov, A. (2020). Are MCDA Methods Benchmarkable? A Comparative Study of TOPSIS, VIKOR, COPRAS, and PROMETHEE II Methods. *Symmetry 2020, Vol. 12, Page 1549*, *12*(9), 1549. https://doi.org/10.3390/SYM12091549

Sayadinia, S., & Beheshtinia, M. A. (2021). Proposing a new hybrid multi-criteria decision-making approach for road maintenance prioritization. *International Journal of Quality & Reliability Management*, *38*(8), 1661–1679. https://doi.org/10.1108/IJQRM-01-2020-0020

Setiawan, H., Istiyanto, J. E., Wardoyo, R., & Santoso, P. (2016). The Group Decision Support System to Evaluate the ICT Project Performance Using the Hybrid Method of AHP, TOPSIS and Copeland Score. *International Journal of Advanced Computer Science and Applications*, *7*(4), 334–341.

Singh, A., Gupta, A., & Mehra, A. (2021). Best criteria selection based PROMETHEE II method. *Opsearch*, *58*, 160–180.

Tajik, M., Makui, A., & Tosarkani, B. M. (2023). Sustainable cathode material selection in lithium-ion batteries using a novel hybrid multi-criteria decision-making. *Journal of Energy Storage*, *66*, 107089. https://doi.org/10.1016/J.EST.2023.107089

Torkzad, A., & Beheshtinia, M. A. (2019). Evaluating and prioritizing hospital service quality. *International Journal of Health Care Quality Assurance*, *32*(2), 332–346. https://doi.org/10.1108/IJHCQA-03-2018-0082

Zanakis, S. H., Solomon, A., Wishart, N., & Dublish, S. (1998). Multi-attribute decision making: A simulation comparison of select methods. *European Journal of Operational Research*, *107*(3), 507–529. https://doi.org/10.1016/S0377-2217(97)00147-1