A Comparison of the Multi-criteria Decision-Making Methods for the Selection of Researchers

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Abstract Multi-criteria decision-making methods (MCDM) have been introduced to make effective decisions under conflicting criteria. This study used AHP-based VIKOR, TOPSIS, and MOORA methods to select two researchers among the twenty-six alternative candidates and to compare the findings of the different MCDM methods. The results showed that the AHP-based VIKOR and TOPSIS methods suggested the selection of the same candidates. However, different methods sorted the candidates in a significantly different order. This study reveals that MCDM methods might not always propose the same solution, although they are still useful in effective decision-making and easy to apply.

Keywords Decision-making · VIKOR · TOPSIS · MOORA · Researcher selection

Introduction

Decision-making is a situation that every individual frequently encounters in both daily and business life. A typical decision-making process involves three stages: the definition of the decision-making problem, the development and use of a decision-making model, and the creation of action plans [24]. Although the decision-making process is completed with the creation of action plans, the adverse effects of the inefficient decision-making process are inevitable to continue [8].

In the literature, several methods have been developed by using different algorithms [12, 30, 31]. As part of these methods, Multi-Criteria Decision-Making (MCDM) methods have been developed to make decisions under conflicting criteria

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[1, 32]. MCDM methods combine many disciplines, predominantly mathematics, and they provide a systematic way of making decisions [14, 18, 24].

Each MCDM method was developed on different algorithms; therefore, they might reach different conclusions. In other words, different methods can suggest the selection of different alternatives. It is, at precisely this point, that the reliability of MCDM methods has been criticized by several researchers [4, 6].

However, despite all criticisms, the MCDM methods have been used in classification, selection, and ranking problems concerning various processes in many different industries. For example, Antmen and Mic [2] used fuzzy TOPSIS and Analytical Hierarchy Process (AHP) methods to select a ventilator in the pediatric intensive care unit. Ozturk and Kaya [23] used fuzzy VIKOR to select personnel in the automotive industry. Bedir and Yalcin et al. [5] used Analytical Network Process (ANP) and PROMETHEE methods to select subcontractors. Soba and Simsek et al. [29] used AHP based VIKOR to select doctoral students. Brauers and Edmundas et al. [8] used the MOORA method to select a contractor. In addition, several other MCDM methods have been used in decision-making. However, among all MCDM methods, TOPSIS, AHP and VIKOR methods were frequently used, and the MOORA method was promoted due to its ease of use and low-time requirement [13, 16, 17, 21, 34].

This study aims to use AHP-based TOPSIS, VIKOR, and MOORA methods for the selection of two researchers to an engineering faculty and to compare the findings of these MCDM methods.

Methodology

Study Design

The design of this study consists of three stages: determining criteria, estimating the criteria weights, and ranking alternatives (Fig. 1).

The determination of the criteria was made by reviewing similar studies in the decision-making literature [15, 17, 19, 22, 26, 28, 29] and conducting meetings with four academic members in the related faculty.

The AHP method was used to calculate the weights for each criterion. Initially, a questionnaire was designed to assess the relative importance of each criterion. In this questionnaire, a scale of 1 to 9 was used to make pairwise comparison [27]. Four faculty members completed the questionnaire, and they reached a consensus on the conflicted responses.

The VIKOR, TOPSIS, and MOORA (MOORA-rate system and MOORA-reference point theory) methods were used to rank the twenty-six candidates based on seven criteria. The application of MCDM methods was carried out using MS Office Excel.

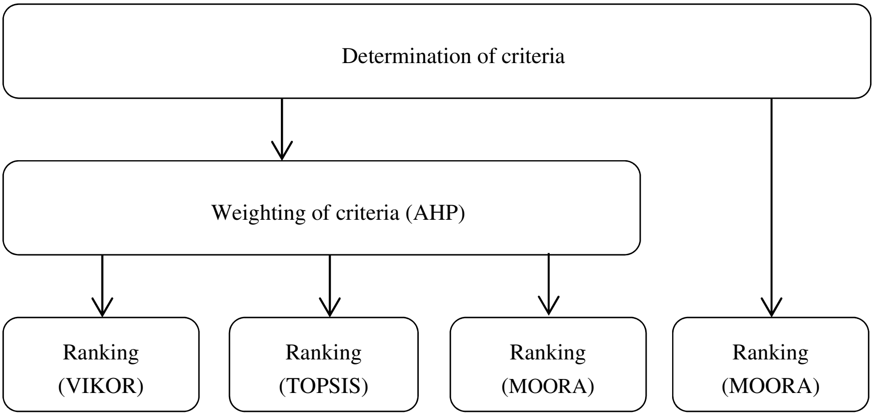

Fig. 1 The research design for the selection of two researchers

The AHP Method

AHP is based on the general measurement theory, and it aims to solve problems identified for a specific purpose. It is possible to describe the AHP method in four stages [27].

Step 1 Creating the hierarchical structure of the decision problem: It starts from the top level. Level 1 represents the goal; level 2 represents the criteria; level 3 shows the sub-criteria, and the lowest level shows the alternatives.

Step 2 Creating the binary comparison matrix: Binary comparison matrices for each level of the hierarchical structure are created by Eq. (1). Here, n criteria $(a_1, a_2, \ldots a_n)$ are compared by using the 1–9 scale of Saaty.

$$\begin{bmatrix} 1 & a_{12} & \ldots & a_{1n} \\ a_{21} & 1 & \ldots & a_{2n} \\ \vdots & \vdots & \ldots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \tag{1}$$

Step 3 Determination of criterion weights: The weight values of each criterion are calculated. For this, the matrix is normalized using Eq. (2) and, then, the weights are calculated by Eq. (3).

$$a_{ij}^{*} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{2}$$

$$w_i = \frac{\sum_{j=1}^{n} a_{ij}^{*}}{n} \tag{3}$$

Step 4 Making consistency calculations: Consistency is calculated to obtain reliable results. The Consistency Rate (CR) is expected to be less than 0.10. For this, λ_{max} is calculated in Eq. (4), the Consistency Index (CI) by Eq. (5), and CR value by Eq. (6). Random Value Index (RI) in Eq. (6) is the value corresponding to n from the RI table.

$$\lambda_{max} = \frac{\sum_{i=1}^{n}\left(\frac{d_i}{w_i}\right)}{n}, \quad [d_i]_{n\times 1} = \left[a_{ij}\right]_{n\times n} \times [w_i]_{n\times 1} \tag{4}$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{5}$$

$$CR = \frac{CI}{RI} \tag{6}$$

The VIKOR Method

The VIKOR method is developed to calculate the closeness of the alternatives to the ideal solution, and, thus, it provides a compromise solution to the problem [20]. It is possible to describe the VIKOR method in five stages:

Step 1 The best f_i^{*} and the worst f_i^{-} values are determined: The decision matrix is created with the scores of the alternatives for each criterion (i = 1, 2,.. n), and the values of f_i^{*} and f_i^{-} are calculated based on the criterion features. Here, Eq. (7a) is for the criterion with the benefit feature and Eq. (7b) for cost.

$$\begin{aligned} f_i^{*} &= max_j x_{ij} \\ f_i^{-} &= min_j x_{ij} \end{aligned} \tag{7a}$$

$$\begin{aligned} f_i^{*} &= min_j x_{ij} \\ f_i^{-} &= max_j x_{ij} \end{aligned} \tag{7b}$$

Step 2 Calculation of S_j and R_j values: S_j (average group score) the score is calculated in Eq. (8) and R_j (worst group score) score in Eq. (9) for each alternative $(j = 1, 2, ..J)$.

$$S_j = \sum_{i=1}^{n} w_i \frac{f_i^{*} - x_{ij}}{f_i^{*} - f_i^{-}} \tag{8}$$

$$R_j = max_i \left[w_i \frac{f_i^{*} - x_{ij}}{f_i^{*} - f_i^{-}} \right] \tag{9}$$

Step 3 Calculation of Q_j value: For alternatives ($j = 1, 2, \ldots J$), the maximum group benefit (Q_j) is calculated by Eq. (10). The parameters S^*, S^-, R^*, R^- required to calculate Q_j are shown by Eq. (11). The v value in Eq. (11) represents the maximum group utility.

$$Q_j = \frac{v(S_j - S^*)}{(S^- - S^*)} + \frac{(1 - v)(R_j - R^*)}{(R^- - R^*)} \tag{10}$$

$$\begin{aligned} S^* &= min_j S_j;\ R^* = min_j R_j \\ S^- &= max_j S_j;\ R^- = max_j R_j \end{aligned} \tag{11}$$

Step 4 Sorting S_j, R_j, Q_j values: These three values obtained by each alternative are sorted from lowest to highest.

Step 5 Checking the conditions: The reliability of the ranking ordering of alternatives is controlled by two conditions: acceptable advantage condition and acceptable stability condition.

Under the condition of acceptable advantage in Eq. (12), A^1 is the first (the lowest value) alternative ($j = 1, 2, \ldots J$) that ranks from lowest to highest and A^2 is the second.

$$Q_{A^2} - Q_{A^1} \geq \frac{1}{j - 1} \tag{12}$$

Under the acceptable stability condition, A^1 is ranked the best by S_j and/or R_j.

When the first (acceptable advantage) of these conditions is met, but the second condition (acceptable stability) is not met, A^1 and A^2 are considered together as a compromised solution.

If the first condition is not met: all of the alternatives from A^1, A^2 A^3… A^m are considered as compromised solutions. The value of m is determined according to Eq. (13).

$$Q_{A^m} - Q_{A^1} < \frac{1}{j - 1} \text{ for maximum } m \tag{13}$$

The TOPSIS Method

The TOPSIS method chooses the alternative that is closest to the ideal solution, but the farthest to the negative ideal solution [11]. It is possible to apply the TOPSIS method in six steps.

Step 1 Calculate the normalized decision matrix: The normalization of the decision matrix is calculated by finding r_{ij} (normalized values) as in Eq. (14). Here, the criteria are specified with i ($i = 1, 2, ..n$)and alternatives with j ($j = 1, 2, ..J$).

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{J} x_{ij}^2}} \quad (14)$$

Step 2 Creating the weighted normalized decision matrix: The weights $(w_1, w_2, \ldots w_n)$ of each criterion $(i = 1, 2, \ldots n)$ are determined by the decision-maker. The weighted normalized value v_{ij} is calculated, as shown by Eq. (15).

$$v_{ij} = w_i r_{ij} \quad (15)$$

Step 3 Determination of the ideal and negative ideal solutions: The ideal solution (A^*) takes the maximum value when associated with benefit criterion (I'), and the minimum value when associated with cost criterion (I'') (Eq. 16a). The negative ideal solution $\left(A^-\right)$ applies the opposite (Eq. 16b).

$$\begin{aligned} A^* &= \left\{v_1^*, v_2^*, \ldots v_n^*\right\} \\ &= \left\{\left(max_j v_{ij} \| \mathrm{i} \epsilon I'\right), \left(min_j v_{ij} \| \mathrm{i} \epsilon I''\right)\right\} \end{aligned} \quad (16a)$$

$$\begin{aligned} A^- &= \left\{v_1^-, v_2^-, \ldots v_n^-\right\} \\ &= \left\{\left(min_j v_{ij} \| \mathrm{i} \epsilon I'\right), \left(max_j v_{ij} \| \mathrm{i} \epsilon I''\right)\right\} \end{aligned} \quad (16b)$$

Step 4 Calculate distance values: The distance from the ideal solution (D_j^*) is calculated by Eq. (17a) by using the Euclidean distance, and the distance from the negative ideal solution (D_j^-) is calculated by Eq. (17b).

$$D_j^* = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^*\right)^2}, \ j = 1, 2, \ldots, J \quad (17a)$$

$$D_j^- = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^-\right)^2}, \ j = 1, 2, \ldots, J \quad (17b)$$

Step 5 Calculation of the relative proximity to the ideal solution: Relative proximity (C_j^*) of alternative a_j to A^* is calculated by Eq. (18).

$$C_j^* = \frac{D_j^-}{\left(D_j^* + D_j^-\right)}, \ j = 1, 2, \ldots, J \quad (18)$$

Step 6 Rank the preference order: The ranking is made from the alternative having the largest C_j^* values (the best alternative) to the lowest.

The MOORA Method

The MOORA method is for multi-objective optimization with discrete alternatives. It has two approaches: the ratio system and reference point theory [7, 8].

The ratio system is carried out in two steps. In the first step, the normalization process is applied by Eq. (19). Here, i represents the objective ($i = 1, 2, \ldots, n$) and j alternative (j = 1, 2, . . . , J).

$$x_{ij}^{*} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{J} x_{ij}^{2}}} \tag{19}$$

In the second step of the ratio system, the evaluation of the degree of the alternative (j) meeting the objective (i) is found by the optimization of the normalized values. Equation (20) is applied depending on the objectives of the criteria (i.e., maximization or minimization).

$$y_{j}^{*} = \sum_{i=1}^{i=g} x_{ij}^{*} - \sum_{i=g+1}^{i=n} x_{ij}^{*} \tag{20}$$

In Eq. (20), $i = 1, 2, \ldots, g$ represents objectives (of the criteria) to be maximized and $i = g + 1, g + 2, \ldots, n$ objectives to be minimized. The ranking order of each alternative is obtained by sorting the values of y_j^* from highest to lowest. The largest y_j^* values will be the best alternative.

Reference point theory measures the distances between alternatives (x_{ij}^*) and a reference point (r_i) by Eq. (21).

$$min_j max_i \left(\left| r_i - x_{ij}^{*} \right| \right) \tag{21}$$

In cases where criteria weights (s_i) are known, x_{ij}^* values in Eq. (20) and r_i and x_{ij}^* values in Eq. (21) are multiplied by the coefficient s_i, as in Eqs. (22) and (23).

$$y_{j}^{*} = \sum_{i=1}^{i=g} s_i x_{ij}^{*} - \sum_{i=g+1}^{i=n} s_i x_{ij}^{*} \tag{22}$$

$$min_j max_i \left(\left| s_i r_i - s_i x_{ij}^{*} \right| \right) \tag{23}$$

Results

In this study, seven criteria were identified, as shown in Table 1. These criteria were used to evaluate twenty-six candidates for the selection of two researchers.

Table 2 represents the evaluation findings of the candidates based on seven criteria. The relevant data for criteria C1 to C4 were directly obtained from the candidates; C5 was from the faculty; C6 was from a university ranking list; C7 were from faculty members.

In this study, AHP was used to calculate the weight of each criterion. Table 3 shows the criterion comparison matrix. Four faculty members participated in a questionnaire to generate the comparison matrix.

The comparison matrix has been normalized by the operations in Eq. (2). Then, the criterion significance weight in Table 4 has been calculated by using Eq. (3). Following that, the consistency ratio was calculated, as CR = 0.03. By reason of $CR < 0.1$, the values obtained are considered to be consistent.

After the calculation of the weights of the criteria, VIKOR was applied to calculate Q_j values; TOPSIS was used to calculate C_j^* values; the MOORA-rate system method was used to calculate y_j^* values; the MOORA-reference point theory method was used to calculate $\max_i\left(\left|r_i - x_{ij}^*\right|\right)$ and $\max_i\left(\left|s_i r_i - s_i x_{ij}^*\right|\right)$ values. Table 5 shows the ranking order of the twenty-six alternatives by using each method.

Table 1 Candidate selection criteria and their explanations

Criterion (C)	Explanation
ALES exam score (C1)	A general exam, including linguistic and mathematics tests. Maximization of this criterion is aimed.
Foreign language score (C2)	Candidates take YDS, YOKDİL, or similar language exams. Maximization of the exam score is aimed.
GPA average (C3)	Undergraduate grade average, in a 4-point system. Maximization of this criterion is aimed.
Work experience (C4)	It shows the years of work experience of candidates. Maximization of this criterion is aimed.
Written Exam (C5)	The candidates take a written exam prepared by the faculty. Maximization of this criterion is aimed.
University ranking (C6)	It represents the candidate's undergraduate or graduate degree university ranking order. Minimisation of this criterion is aimed.
Job fit (C7)	It represents the closeness of the candidate's fit to the applied program by assigning a score between 1 (the worst) and 5 (the best). Maximization of this criterion is aimed.

Table 2 Evaluation of candidates in terms of criteria

Alternative	C1	C2	C3	C4	C5	C6	C7
A1	90	70	3.2	6	75	12	4
A2	85	60	3.5	3,5	80	45	4
A3	96	80	2.7	5	85	34	1
A4	75	67	2.8	6	75	56	2
A5	76	70	2.9	7	70	89	3
A6	68	65	3	1	85	34	4
A7	89	75	3.1	2	70	5	5
A8	67	55	3.2	2	65	17	4
A9	75	60	2.88	3	60	34	3
A10	72	55	2.9	3	75	54	3
A11	70	57	3.05	4	70	23	3
A12	65	62	3.1	8	55	78	4
A13	65	75	3.15	10	50	32	4
A14	70	70	3.2	5	45	41	4
A15	75	65	3.4	4	56	53	4
A16	80	60	3.6	3.5	70	23	5
A17	75	60	2.7	12	65	61	3
A18	94	72	2.6	10	50	19	1
A19	78	70	2.5	8	45	10	1
A20	67	68	2.4	15	65	5	2
A21	85	65	2.8	5	55	12	2
A22	70	64	2.9	2	50	15	1
A23	75	62	3	1	60	16	5
A24	80	60	2.65	1	65	5	3
A25	80	58	2.75	1.5	70	45	2
A26	75	60	3.25	2	65	33	2

Table 3 Criterion comparison matrix

Criterion	C1	C2	C3	C4	C5	C6	C7
C1	1	0.5	3	2	0.25	0.5	0.2
C2	2	1	3	2	0.5	2	0.3
C3	0.33	0.33	1	0.5	0.25	0.33	0.2
C4	0.5	0.5	2	1	0.33	0.5	0.2
C5	4	2	4	3	1	2	0.5
C6	2	0.5	3	2	0.5	1	0.5
C7	5	3	5	4	2	2	1

Table 4 The weight of importance of each criterion

Criterion (i)	C1	C2	C3	C4	C5	C6	C7
Weight (w_i)	0.09	0.14	0.04	0.07	0.22	0.12	0.32

Table 5 The ranking order of alternatives with the use of VIKOR, TOPSIS, and MOORA methods

Alternatives	VIKOR Qj, v = 0.5	TOPSIS Cj	MOORA-rate	MOORA-reference	MOORA-weighted reference
A1	1	1	1	17	1
A2	3	5	4	15	1
A3	4	7	6	10	22
A4	12	15	16	8	14
A5	11	19	20	7	1
A6	17	6	7	24	1
A7	2	2	13	19	1
A8	21	11	12	19	1
A9	15	18	19	17	12
A10	18	14	17	17	1
A11	19	10	11	13	1
A12	26	25	24	4	19
A13	24	13	2	2	21
A14	23	24	23	10	25
A15	14	20	18	13	18
A16	5	3	3	15	1
A17	13	9	9	1	1
A18	10	16	14	5	22
A19	22	22	25	5	25
A20	20	4	5	3	14
A21	8	17	15	10	19
A22	25	26	26	19	22
A23	9	8	8	24	12
A24	6	12	10	24	1
A25	7	21	21	23	14
A26	16	23	22	19	14

Discussion and Conclusion

This study was conducted to select two researchers to an engineering faculty and to compare the findings of the different methods. The findings revealed that the VIKOR

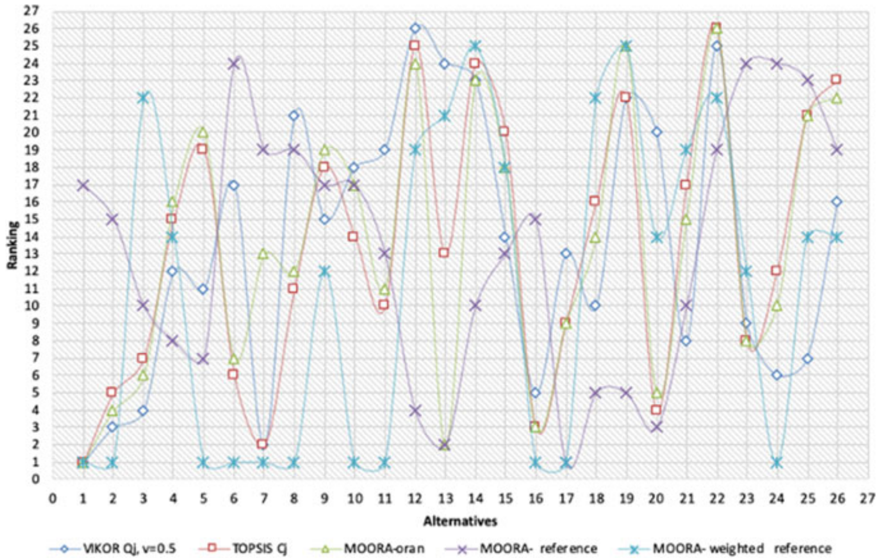

Fig. 2 Comparative ranking results of VIKOR, TOPSIS and MOORA methods

and TOPSIS methods suggest the selection of the same candidates. However, the ranking order of the rest of the candidates was considerably different. Moreover, the MOORA-reference method suggests the selection of entirely different candidates. Figure 2 illustrates the comparative ranking orders for twenty-six alternatives.

In this respect, although MCDM methods are useful to assist in decision-making, they might not always be reliable. It should be taken into account that MCDM methods might not always give the best results. Several researchers have criticized the use of MCDM methods from this perspective [4, 9, 32]. Here, two points should be mentioned. Firstly, MCDM methods have been built on linear mathematical algorithms. Decision-making might depend on the conditions, and thus, the use of linear methods might not fit well in real-life decisions. Individuals might use a non-linear algorithm when making decisions. Indeed, in real life, the decision-making process is rather complex. Secondly, the selection of the criteria and the evaluation of the candidates were based on expert judgments, which can be subjective. Researchers suggested using fuzzy logic to reduce the subjectivity and deal with uncertainty [3, 15, 23]. However, the use of fuzzy logic would still not solve the problem with the dynamic and non-linear features of the decision-making process. At this point, non-linear decision-making methods might provide more reliable results [10, 25, 33].

However, despite their limitations, MCDM methods have still been used to support decision-making due to their simplicity. Future studies might investigate the ideal selection of MCDM methods for specific conditions.

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