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A COMPARATIVE ANALYSIS OF THE RANK REVERSAL PHENOMENON IN THE EDAS AND TOPSIS METHODS

Abstract. *The rank reversal (RR) phenomenon could occur when new information about alternatives or criteria is added to the decision space of a discrete multi-criteria decision-making (MCDM) problem. If this addition leads to a change in the original rank of alternatives, the RR phenomenon occurs. In this study, we analyze the RR phenomenon in a new MCDM method called EDAS (Evaluation based on Distance from Average Solution). For this purpose, three RR indices are defined, and the efficiency of the EDAS method is compared with the TOPSIS method through a simulation-based analysis. The results show that the EDAS method is more efficient than the TOPSIS method with respect to the defined RR measures.*

Keywords: *rank reversal, multi-criteria decision-making, MCDM, EDAS, TOPSIS.*
JELClassification:C02, C44, C61, C63.

1. Introduction

In real-world decision-making problems, we usually need to evaluate some alternatives with respect to multiple criteria. To deal with such problems, multi-

DOI: 10.24818/18423264/52.3.18.08

criteria decision-making (MCDM) techniques and methods are very applicable. In recent decades, many researchers have studied on this field and proposed different MCDM methods such as Simple Additive Weighting (SAW) (MacCrimon, 1968), Analytic Hierarchy Process (AHP) (Saaty, 1980), ELimination Et ChoixTraduisant la REalité (ELECTRE) (Roy, 1968),Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE) (Mareschal and Brans, 1992); Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Hwang and Yoon, 1981), VlseKriterijumskaOptimizacija I KompromisnoResenje (VIKOR) (Opricovic, 1998), etc. Interested readers are referred to some recent review papers about developments and applications of the methods in different fields. Various MCDM techniques and their applications were reviewed by Mardani *et al.* (2015), a comprehensive review of MCDM techniques in fuzzy environment was provided by Kahraman et al. (2015). Later, a broad overview of techniques with emphasis to application in supply chains was provided by KeshavarzGhorabaee *et al.* (2017a).

The rank reversal (RR) phenomenon is an important issue in decision-making processes with multiple criteria and could occur in different MCDM methods. Most of the studies in this field have been done on the AHP method (Barzilai and Golany, 1994; Schenkerman, 1994; Stam and Silva, 1997; Triantaphyllou, 2001; Wang and Elhang, 2006; Saaty and Sagir, 2009). Maleki and Zahir(2013) presented a comprehensive literature review of the rank reversal phenomenon in the AHP method. Some studies have also been performed on the RR phenomenon in the other MCDM methods including PROMETHEEand TOPSIS(Mareschal*et al*., 2008; García-Cascales and Lamata, 2012; Verly and De Smet, 2013). A usual form of this phenomenon occurs when a decision maker is confronted with one or more new alternatives that are not involved in the initial step of the decision-making process. The performance of the new alternative(s) is usually unpredictable, so the decision maker should be ready to handle the changes in final ranking of alternatives. The analysis of RR phenomenon can help the decision-maker to deal with such a situation.

EDAS is a new MCDM method which proposed by KeshavarzGhorabaee*et al.* (2015). In this method, the desirability of an alternative is determined based on positive and negative distances of it from a reference solution called the average solution. This method has been applied and extended by some researchers since its introduction. Extensions of the method with grey numbers (Stanujkic*et al*., 2017), neutrosophic numbers (Peng and Liu, 2017), intuitionistic (Kahraman*et al*., 2017) and interval type-2 fuzzy sets (KeshavarzGhorabaee*et al*., 2017b, 2017c) have recently been proposed. However, the RR phenomenon has not been examined in this method. Because of newness of the EDAS method, assessing different characteristics of it can be useful for future studies. In this study, the RR phenomenon is assessed based on addition of a new alternative. Three indices are defined to measure the frequency of occurrence, frequency of occurrence in first rank and intensity of occurrence of the RR phenomenon. An analysis is made by simulation of the decision data in different numbers of alternatives and criteria, and the EDAS method is compared with the TOPSIS method with respect to the defined indices. The results show that the efficiency of the EDAS method is more than the TOPSIS method when the RR phenomenon occurs.

The rest of this paper is organized as follows. In Section 2, the steps of multi-criteria decision-making process with the EDAS and TOPSIS methods are summarized. Also the framework of the analysis is described in this section. In Section 3, results of the analysis are presented. Finally, the conclusions are discussed in Section 4.

2.Methodology

Suppose that we have n alternatives ($\mathcal{A}_1$ to $\mathcal{A}_n$) and m criteria ($\mathcal{C}_1$ to $\mathcal{C}_m$), and the weight of each criterion ($w_j,\ j \in \{1,2,\dots,m\}$) is known. Accordingly, the decision-matrix is defined as follows:

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1j} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2j} & \dots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{im} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nj} & \cdots & x_{nm} \end{bmatrix} \tag{1}$$

Based on the decision-matrix defined, the steps of the EDAS and TOPSIS methods are summarized in this section. Then, a framework is presented to perform the analysis of the RR phenomenon.

2.1. The EDAS method

As previously mentioned, this method is proposed by Keshavarz Ghorabaee *et al.* (2015). The EDAS method was applied to the inventory classification problem in its first introduction; however, the efficiency of this method for dealing with MCDM problems was also verified. In the EDAS method, the alternatives of an MCDM problem are evaluated based on positive and negative distances from an average solution. An alternative which has higher values of positive distances and lower values of negative distances from the average solution is a more desirable alternative according this method. The steps for using the EDAS method are as follows:

Step 1. Calculation of the elements of average solution ($\mathcal{g}_j$):

$$\mathcal{g}_j = \frac{\sum_{i=1}^{n} x_{ij}}{n} \tag{2}$$

Step 2. Determination of the positive ($\mathcal{P}_{ij}^{d}$) and negative ($\mathcal{N}_{ij}^{d}$) distances:

DOI: 10.24818/18423264/52.3.18.08

$$\mathcal{P}_{ij}^{d} = \begin{cases} \dfrac{max\left(0, x_{ij} - g_j\right)}{g_j} & if\ j \in B \\ \dfrac{max\left(0, g_j - x_{ij}\right)}{g_j} & if\ j \in C \end{cases} \tag{3}$$

$$\mathcal{N}_{ij}^{d} = \begin{cases} \dfrac{max\left(0, g_j - x_{ij}\right)}{g_j} & if\ j \in B \\ \dfrac{max\left(0, x_{ij} - g_j\right)}{g_j} & if\ j \in C \end{cases} \tag{4}$$

where B and C are the sets of benefit and cost criteria, respectively.

Step 3. Computation of the weighted summation of the distances:

$$\mathcal{P}_i^w = \sum_{j=1}^{m} w_j \mathcal{P}_{ij}^d \tag{5}$$

$$\mathcal{N}_i^w = \sum_{j=1}^{m} w_j \mathcal{N}_{ij}^d \tag{6}$$

Step 4. Normalization of the values of the weighted summations:

$$\mathcal{P}_i^n = \frac{\mathcal{P}_i^w}{\max_k \mathcal{P}_k^w} \tag{7}$$

$$\mathcal{N}_i^n = 1 - \frac{\mathcal{N}_i^w}{\max_k \mathcal{N}_k^w} \tag{8}$$

Step 5. Calculation of the appraisal score of each alternative:

$$\mathcal{S}_i = \frac{1}{2}\left(\mathcal{P}_i^n + \mathcal{N}_i^n\right) \tag{9}$$

Step 6. Rank the alternatives according to decreasing values of $\mathcal{S}_i$.

2.2. The TOPSIS method

The TOPSIS method is a popular MCDM method which has been used in many real-world problems and extended in different uncertain environments. Interested readers are referred to review of the TOPSIS method by Behzadian *et al.* (2012). In this study, a classic version of this method presented by Hwang and Yoon (1981) is used for analysis. In the TOPSIS method, the evaluation process of alternatives is made with respect to the distances from the ideal and anti-ideal solutions. The procedure of this method is presented in the following steps:

Step 1. Determination of the normalized values of the decision-matrix:

$$\bar{x}_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \tag{10}$$

Step 2. Calculation of the weighted normalized values:

$$\bar{x}_{ij}^{w} = w_j \times \bar{x}_{ij} \tag{11}$$

Step 3. Determination of the ideal and anti-ideal solutions based on the weighted normalized values:

$$I^{*} = \{\bar{x}_1^{w*}, \dots, \bar{x}_m^{w*}\} = \left\{\left(\max_i \bar{x}_{ij}^{w} \mid j \in B\right), \left(\min_i \bar{x}_{ij}^{w} \mid j \in C\right)\right\} \tag{12}$$

$$I^{-} = \{\bar{x}_1^{w-}, \dots, \bar{x}_m^{w-}\} = \left\{\left(\min_i \bar{x}_{ij}^{w} \mid j \in B\right), \left(\max_i \bar{x}_{ij}^{w} \mid j \in C\right)\right\} \tag{13}$$

where B and C are the sets of benefit and cost criteria, respectively.

Step 4. Calculation of the Euclidean distance of alternatives from the ideal (D_i^*) and anti-ideal (D_i^-) solutions:

$$D_i^{*} = \sqrt{\sum_{j=1}^{m} \left(\bar{x}_{ij}^{w} - \bar{x}_j^{w*}\right)^2} \tag{14}$$

$$D_i^{-} = \sqrt{\sum_{j=1}^{m} \left(\bar{x}_{ij}^{w} - \bar{x}_j^{w-}\right)^2} \tag{15}$$

Step 5. Calculation of the closeness coefficient (CC_i) of each alternative:

$$CC_i = \frac{D_i^-}{D_i^* + D_i^-} \tag{16}$$

Step 6. Rank the alternatives in decreasing order of the closeness coefficient values.

DOI: 10.24818/18423264/52.3.18.08

2.3. RR phenomenon analysis

In this study, to analyze the RR phenomenon, we assume a common situation in which a new alternative is added to the MCDM problem. In this regard, we define three indices as follows:

- ***Percentage of the Frequency of Occurrence (PFO):*** This index measures the ratio of the occurrence of the RR phenomenon in a given number of simulations.
- ***Percentage of the Frequency of Occurrence in First rank (PFOF):*** This index measures the ratio of the occurrence of the RR phenomenon in a given number of simulations where the first rank is changed.
- ***Intensity of Occurrence (IO):***This index measures the intensity of the occurrence of the RR phenomenon in a given number of simulations by computing the average changes (AC) in different ranks. Suppose that we have an MCDM problem with n alternatives, and $R_i^{(1)}$ denote the original rank of ith alternative and $R_i^{(2)}$ shows the rank of ith alternative after occurrence of the RR phenomenon. Then the AC is computed as follows:

$$AC = \frac{1}{n}\sum_{i=1}^{n}\left|R_i^{(1)} - R_i^{(2)}\right| \tag{17}$$

According to the defined indices, the following algorithm is used to analyze the RR phenomenon:

Step 1: Define the number of alternatives (n_s) and criteria (m_s) for the simulation process.

Step 2: Start the simulation process, set iteration counter to one (r=1), set the counter of the occurrence of the RR phenomenon to zero ($CO = 0$), set the counter of the occurrence of the RR phenomenon in the first rank to zero ($COF = 0$), set the total value of the average changes to zero ($TAC = 0$), and define the total number of iterations (ITR).

Step 3: Define the first MCDM problem (P_1) by generating a random decision-matrix with the dimension $n_s \times m_s$ and elements in the range of α to β, and set the weight of all criteria to $\frac{1}{m_s}$.

Step 4: Define the second MCDM problem (P_2) by adding a new alternative to P_1. This addition is made by generating a row with the dimension $1\times m_s$ and elements in the range of α to β and joining this row to the matrix of P_1 (P_2 has the dimension $(n_s + 1) \times m_s$).

Step 5: Solve P_1 and P_2 by an MCDM method and determine the rank of each alternative. Suppose that $R_i^{(1)}$ and $R_i^{(2)}$ denote the rank of ith in the first and second MCDM problems, respectively ($i = 1,2, \dots, n_s$).

Step 6: If there is any difference between $R_i^{(1)}$ and $R_i^{(2)}$ ($i = 1,2, \dots, n_s$), increase the value of CO by one ($CO = CO + 1$), calculate the value of AC using Eq. (17), increase the value of TAC by the calculated AC ($TAC = TAC + AC$). If any change occurs in the first rank, increase COF by one ($COF = COF + 1$).

Step 7: Increase the iteration counter by one ($r = r + 1$). If the iteration counter is less than or equal to ITR ($r \le ITR$), go to Step 3, otherwise continue.

Step 8: Calculate the values of PFO, PFOF and IO as follow:

$$PFO = \frac{CO}{ITR} \times 100 \tag{18}$$

$$PFOF = \frac{COF}{ITR} \times 100 \tag{19}$$

$$IO = \frac{TAC}{ITR} \tag{20}$$

3. Comparative analysis

Using the methodology of analysis of the RR phenomenon presented in the previous section, we make a comparison between the EDAS and TOPSIS methods in this section.

To perform the proposed algorithm, 64 modes are defined with respect to 8 values for the number of alternatives ($n_s = \{5, 10,15,30,50,100,200,500\}$) and 8 values for the number of criteria ($m_s = \{5, 10,15,30,50,100,200,500\}$), and the simulation is run for ITR=10000 times with the values $\alpha = 1$ and $\beta = 100$. Therefore $64 \times 10000 = 640000$ MCDM problems are solved using the EDAS and TOPSIS methods.

Based on the proposed algorithm and Eqs. (18) to (20), the values of PFO, PFOF and IO are determined in each mode of each method. Table 1 shows the values of PFO for the EDAS and TOPSIS methods.

According to Table 1, the values of PFO in the EDAS method is lower than or equal to the values of PFO in the TOPSIS method in all modes. Accordingly, we can say that the efficiency of the EDAS method is more than the TOPSIS method with respect to this index. Fig. 1 shows the variation of this index in $n_s =$

DOI: 10.24818/18423264/52.3.18.08

5regarding changes in the number of criteria, and Fig. 2 represents the variation of PFO in $m_s = 5$concerning changes in the number of alternatives.

Table 1. The values of PFO for the EDAS and TOPSIS methods.

	n_s \ m_s	5	10	15	30	50	100	200	500
EDAS	5	27.68	29.95	30.25	31.26	31.81	32.4	32.24	33.08
	10	51.64	54.61	54.47	55.89	56.41	57.27	56.99	56.89
	15	67.87	68.7	70.86	72.14	71.42	72.39	71.98	72.78
	30	89.19	91.01	91.63	92.61	92.7	92.51	92.55	92.72
	50	97.29	97.82	98.24	98.34	98.62	98.74	98.76	98.62
	100	99.78	99.95	99.95	99.93	99.97	100	100	100
	200	99.88	99.99	100	100	100	100	100	100
	500	100	100	100	100	100	100	100	100
TOPSIS	5	35.65	39.97	41.7	42.71	42.99	43.83	44.25	44.15
	10	62.66	69.22	70.43	72.03	73.45	73.23	73.09	74.37
	15	77	83.12	84.2	85.64	86.64	86.44	87.04	87.68
	30	93.53	96.8	97.42	98.14	98.17	98.63	98.58	98.56
	50	98.06	99.66	99.75	99.84	99.86	99.88	99.93	99.92
	100	99.86	99.98	100	100	100	100	100	100
	200	99.94	100	100	100	100	100	100	100
	500	100	100	100	100	100	100	100	100

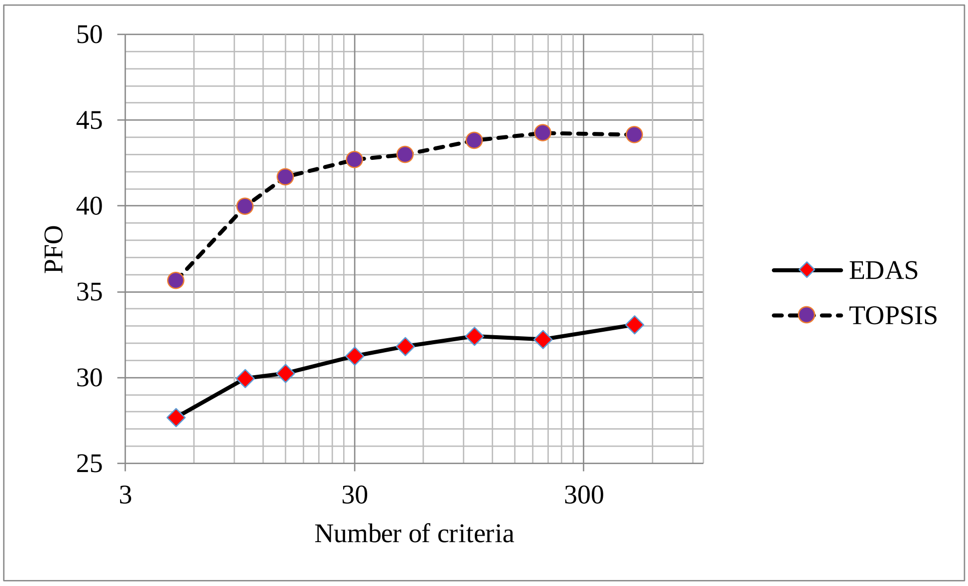

Figure 1. Variation of PFO in $n_s = 5$.

It can be seen that the value of the PFO increase when we have higher number of alternatives and/or criteria. However, if we have more than 50 alternatives, the possibility of the occurrence of RR phenomenon is very high in both the EDAS and TOPSIS methods.

In Table 2, the values of PFOF for the EDAS and TOPSIS methods can be seen.

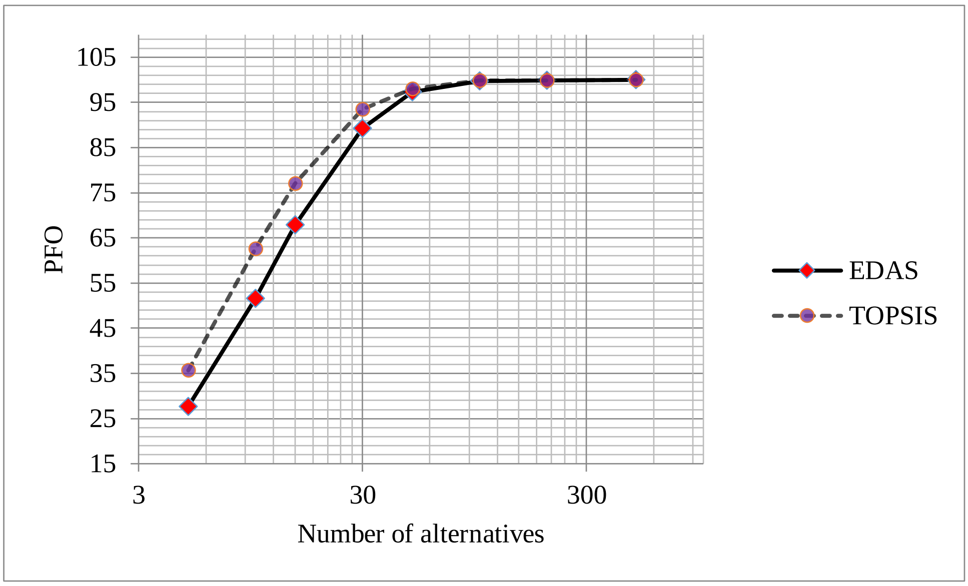

Figure 2. Variation of PFO in $m_s = 5$.

Table 2. The values of PFOF for the EDAS and TOPSIS methods.

		m_s							
	n_s	5	10	15	30	50	100	200	500
EDAS	5	6.78	7.27	7.55	7.62	8.11	8.04	8.6	8.41
	10	4.07	4.94	4.96	4.66	4.93	4.91	5.09	4.9
	15	3.05	3.53	3.88	4.13	3.93	3.83	3.73	3.82
	30	1.95	2.3	2.2	2.26	1.95	2.17	2.02	2.26
	50	1.12	1.13	1.28	1.43	1.38	1.56	1.56	1.68
	100	0.63	0.83	0.72	0.71	0.86	0.9	0.83	0.67
	200	0.27	0.44	0.54	0.4	0.58	0.42	0.42	0.38
	500	0.08	0.11	0.17	0.22	0.16	0.26	0.17	0.2
TOPSIS	5	8.61	10.18	10.94	11.02	11.6	11.37	11.94	11.71
	10	5.9	7.1	7.11	7.49	7.76	7.72	8.05	8.33
	15	3.91	5.32	5.57	5.94	6.08	6.19	5.76	6.38
	30	2.06	2.52	2.8	3.27	3.75	3.23	3.25	3.78
	50	1.18	1.95	2.1	2.03	2.43	2.46	2.35	2.24
	100	0.79	0.93	1.25	1.21	1.13	1.33	1.47	1.2
	200	0.33	0.5	0.65	0.58	0.52	0.62	0.68	0.86
	500	0.11	0.13	0.23	0.24	0.19	0.3	0.22	0.29

DOI: 10.24818/18423264/52.3.18.08

In Table 2, we can see that PFOF values of the EDAS method are lower than those of the TOPSIS method in most cases. Hence the EDAS method is more efficient than the TOPSIS method with regard to this index. For clarification, in Fig. 3 and Fig. 4, we depict the variation of PFOF with respect to changes in the number of alternatives and criteria. According to these figures, the value of PFOF has a direct relationship with the number of criteria and an inverse relationship with the number of alternatives.

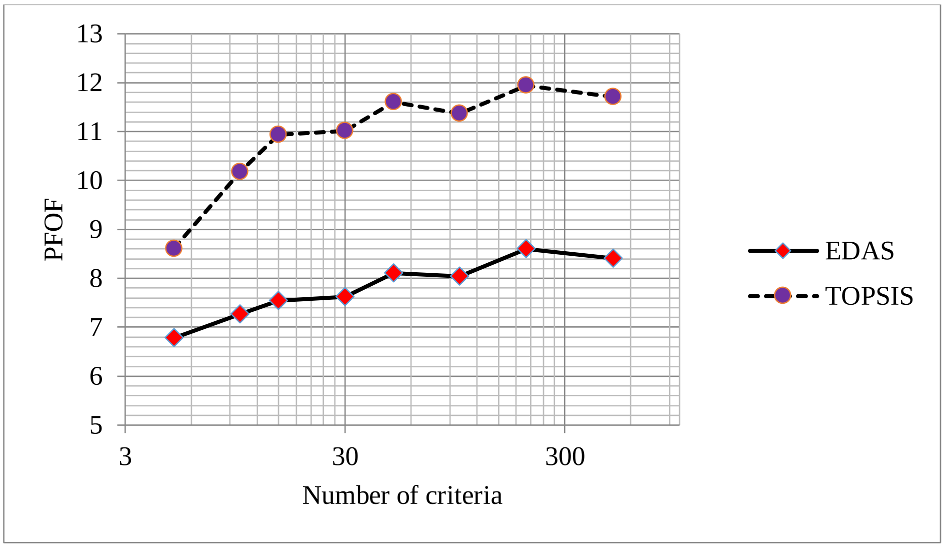

Figure 3. Variation of PFOF in $n_s = 5$.

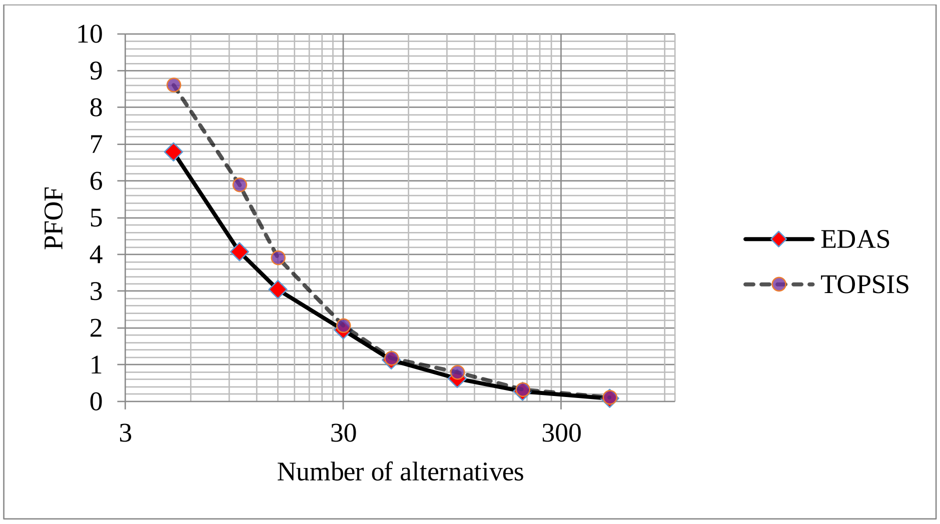

Figure 4. Variation of PFOF in $m_s = 5$.

The values of the IO index, which shows the intensity of the occurrence of the RR phenomenon, are represented in Table 3. According to this table, the values of IO in the EDAS method are lower than the values of IO in the TOPSIS method in all modes, so the EDAS method behaves in a more efficient way with respect to this index. Fig. 5 and Fig. 6 are depicted to clarify the trend of variation of the IO index based on changes in the number of alternatives and criteria. It can be concluded that the value of IO has a direct relationship with both of the number of alternatives and criteria.

Table 3. The values of IO for the EDAS and TOPSIS methods.

		m_s							
	n_s	5	10	15	30	50	100	200	500
EDAS	5	0.1284	0.1425	0.1432	0.1475	0.1496	0.1530	0.1508	0.1562
	10	0.1510	0.1607	0.1592	0.1641	0.1645	0.1659	0.1645	0.1663
	15	0.1589	0.1629	0.1676	0.1686	0.1676	0.1695	0.1698	0.1695
	30	0.1666	0.1732	0.1733	0.1725	0.1735	0.1741	0.1722	0.1723
	50	0.1695	0.1742	0.1769	0.1763	0.1749	0.1750	0.1759	0.1728
	100	0.1716	0.1770	0.1784	0.1788	0.1769	0.1750	0.1750	0.1745
	200	0.1725	0.1789	0.1799	0.1788	0.1774	0.1769	0.1771	0.1759
	500	0.1720	0.1769	0.1799	0.1773	0.1764	0.1775	0.1768	0.1763
TOPSIS	5	0.1742	0.2029	0.2098	0.2157	0.2174	0.2215	0.2241	0.2245
	10	0.2091	0.2389	0.2456	0.2497	0.2594	0.2591	0.2592	0.2646
	15	0.2207	0.2453	0.2534	0.2623	0.2657	0.2676	0.2667	0.2702
	30	0.2229	0.2492	0.2627	0.2652	0.2692	0.2749	0.2744	0.2762
	50	0.2260	0.2518	0.2601	0.2666	0.2705	0.2721	0.2744	0.2750
	100	0.2282	0.2513	0.2571	0.2652	0.2676	0.2696	0.2713	0.2713
	200	0.2276	0.2508	0.2586	0.2645	0.2658	0.2684	0.2694	0.2699
	500	0.2280	0.2513	0.2572	0.2634	0.2656	0.2667	0.2684	0.2684

DOI: 10.24818/18423264/52.3.18.08

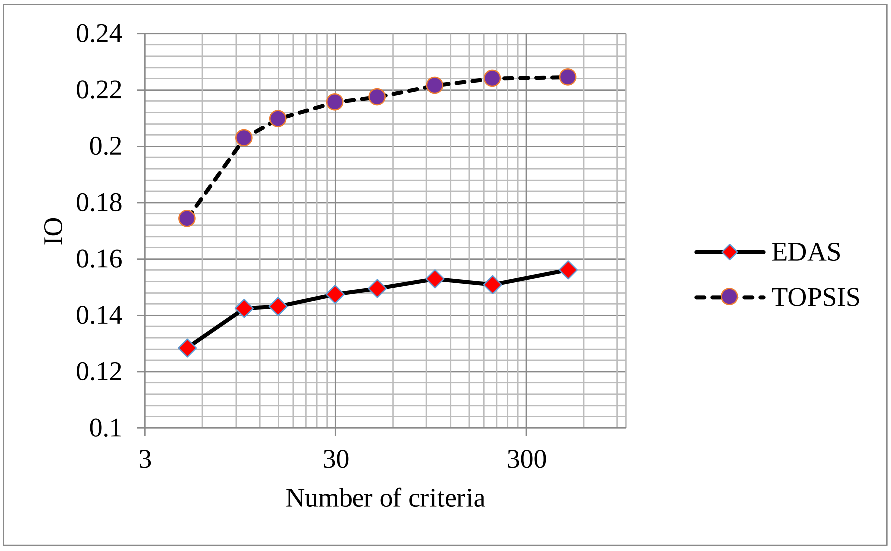

Figure 5. Variation of IO in $n_s = 5$.

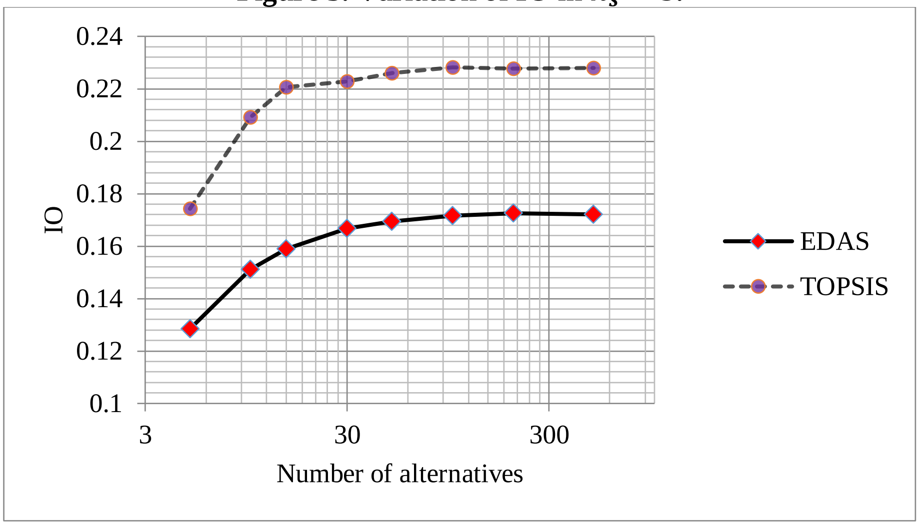

Figure 6. Variation of IO in $m_s = 5$.

4. Conclusions

Multi-criteria decision-making methods are very useful to deal with the real-world decision-making problems. However, they have also some weaknesses to handle the problems. The rank reversal phenomenon is one of the important issues in MCDM methods. This phenomenon occurs when new information in decision process leads to some changes in the final decision. In this study, we have proposed three indices and a simulation-based algorithm to analyze the RR phenomenon. According to the proposed approach, the efficiency of EDAS as a new MCDM method has been compared with the classic TOPSIS method. The results of the analysis show that the EDAS method is more efficient than the TOPSIS method in the three indices defined. On the other hand, the possibility of the occurrence of the RR phenomenon in both of the EDAS and TOPSIS methods is very high when we have more than 50 alternatives.

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