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Interval number multi-attribute decision-making method based on TOPSIS

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Abstract For multi-attribute decision-making problems with interval numbers whose attribute weights are completely unknown, it is difficult to compare the value of interval numbers. So this paper proposes a method based on TOPSIS and the weighted parameter to deal with it. Firstly, this paper transforms the interval number matrix into two exact number matrices which reduces sorting complexity. Secondly, a parameter is given when determining the weights with entropy weight in order to reflect all the information of the interval numbers. Then TOPSIS is used to determine the order of each scheme. In addition, the average value of the ranking number is used to reflect the actual situation better. Finally, the analysis of the car purchase case shows the proposed method is feasible and practical. And the comparative analysis with the other method based on practical application dataset demonstrates the proposed method is stable and effective.

1. Introduction

Due to the complex objective world and its uncertainty, it is difficult to describe the relevant attributes in decision-making problems with exact numbers. To make the model closer to the facts, interval numbers without clear preference information are often used when processing data, thus causing interval number multi-attribute decision-making problems, such as [1].

At present, the research on such problems has gained attention from scholars at home and abroad. The research focuses on the following four aspects. The first is to sort the interval numbers according to possibility degree, relative superiority degree. Li Z W [2] used relative superiority degree and defined a new sorting vector to rank interval numbers. Li D Q [3] found the ranking method of possibility degree may obtain contrary results to the meaning of possibility degree. So a revised ranking by Boolean matrix was discussed. But the scientificity of the new method needs to be further verified. Yao N [4] defined an interval number ranking method considering symmetry axis compensation which consider multiple attitudes of decision makers with different risk appetites. Firozja, M [5] proposed a new interval distance of two fuzzy numbers that satisfy on metric properties. The second is to determine the weight by studying the application of entropy weight method [6,7]. Dong P Y [8] proposed a combined weight method. Yue Z L [9] developed a determining weights method for group decision-making problems which each individual decision information is interval numbers. The third is to sort the schemes with the help of projection, grey relation analysis,

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etc [8,10–18]. The forth is to propose the methods for group decision-making problems [9,19,20].

Since it is not easy to compare the value of interval numbers, interval numbers are replaced with midpoint and length in document Sun [9] and left and right end points in document [10]. However, both documents determine the final scheme sorting simply with one attribute weight. So the information of interval numbers has not been fully applied. In fact, interval numbers can also be expressed by the left end point and length. So it is possible to convert an interval number into two exact numbers which are left end point and length when a decision with interval number is made. Meanwhile, in order to fully apply the information of interval numbers, the parameter can be given to the weight in the decision-making process. Then several values can be given to the parameter within its feasible range. If parameter value is different, the sorting result may be different. So the mean values of the ranking can be used to determine the final scheme sorting and the sorting results at this time are more faithful to the facts.

This paper first converts the interval number decision-making matrix into two exact number matrices. Then the respective attribute weights for these two exact number matrices are determined through the entropy weight method and the convex combination of these two weight vectors are used which is considered as the weight of each attribute in the decision-making problem with interval number. At this time, various possible values can be given to the convex combination coefficient to calculate the composite attribute value of each scheme. TOPSIS method can be used to determine the order of the scheme. Finally, numbers of the scheme ranking corresponding to the parameter values in the combination weight are averaged. The smaller the average value is, the better the ranking of the scheme will be.

The structure of this paper is organized as follows. Section 2 briefly gives the hypotheses of decision-making. Then, a decision-making method is proposed in detail. In Section 3, the proposed method is used to the car purchase case. Moreover, we compare it with the other methods to show the proposed method in this paper is feasible and effective. Finally conclusions and further work are given in Section 4.

2. The method based on TOPSIS

2.1. Hypotheses

(1) The decision makers are “complete rationality”.
(2) The natural states are determinate.
(3) Attributes are independent of each other.

2.2. Decision method based on TOPSIS

In order to facilitate the description of the follow-up content, the following marks are made for the problems with m schemes and n attributes.

The set of schemes available for selection is noted to be $X = \{X_1, X_2, \cdots, X_m\}$. Each scheme is evaluated based on n attributes and the set of attributes is $S = \{S_1, S_2, \cdots, S_n\}$. The weight vector of the attributes is $w = \{\omega_1, \omega_2, \cdots, \omega_n\}$, where $\sum_{j=1}^{n}\omega_j = 1$. The decision-making matrix is $\tilde{A} = (\tilde{a}_{ij})_{m\times n}$, where $\tilde{a}_{ij}$means the evaluation values of the ith scheme under the jth attribute, which are interval numbers, $i = 1, 2, \cdots, m$, $j = 1, 2, \cdots, n$.

Definition 2.1. Li [1] A closed interval $\tilde{a} = [a^L,\ a^U]$ is called the interval number, and $l_{\tilde{a}} = a^U - a^L$ is the length of the interval number$\tilde{a}$, where $a^L \leqslant a^U \in R$. When$a^L = a^U$, $\tilde{a}$ degenerates into a real number.

Without loss of general, the following discussions are all about positive interval numbers. Namely, the left end point of an interval number is greater than 0.

Definition 2.2. Li [2] The distance of interval numbers between $\tilde{a} = [a^L,\ a^U]$ and $\tilde{b} = [b^L,\ b^U]$ is

$$\| \tilde{a} - \tilde{b} \| = \sqrt{\frac{(a^L - b^L)^2 + (a^U - b^U)^2}{2}}. \tag{1}$$

Considering an interval number multi-attribute decision-making problem, the specific steps of scheme sorting are given as follows.

Step 1 Construct the left end point matrix $B = (b_{ij})_{m\times n}$and length matrix $C = (c_{ij})_{m\times n}$ of the decision-making matrix $\tilde{A} = (\tilde{a}_{ij})_{m\times n}$, where

$$b_{ij} = a_{ij}^L, \quad i = 1, 2, \cdots, m, j = 1, 2, \cdots, n \tag{2}$$

$$c_{ij} = a_{ij}^U - a_{ij}^L, \quad i = 1, 2, \cdots, m, j = 1, 2, \cdots, n \tag{3}$$

Step 2 Normalize matrices B and C with the linear transformation method in document [18] to obtain the matrices R_1 andR_2.

Step 3 Uniformize the matrices R_1 and R_2 in columns separately, and determine the weight of each attribute in matrix B and matrix C in terms of entropy weight method provided in Ref. [21]. The weight vectors are marked as$w^B = (w_1^B, w_2^B, \cdots, w_n^B)^Tandw^C = (w_1^C, w_2^C, \cdots, w_n^C)^T$. Let$w = (w_1, w_2, \cdots, w_n)^T, = \alpha \cdot w^B + (1-\alpha)\cdot w^C$where $\alpha \in [0,\ 1]$. Thus w is the weight of each attribute in the interval number decision-making matrix $\tilde{A}$.

Step 4 Normalize the original decision-making matrix $\tilde{A}$ to get the matrix $\tilde{R} = (\tilde{r}_{ij})_{m\times n}$ with the method in Ref. [6].

Step 5 Calculate the weighted comprehensive attribute value of each scheme to obtain the matrix $\tilde{Z} = (\tilde{z}_{ij})_{m\times n}$, where

$$\tilde{z}_{ij} = w_j \cdot \tilde{r}_{ij} = [z_{ij}^L, z_{ij}^U], \quad i = 1, 2, \cdots, m, j = 1, 2, \cdots, n \tag{4}$$

Step 6 Determine the positive ideal solution according to $\tilde{z}^+ = ([\max_i\{z_{i1}^L\}, \max_i\{z_{i1}^U\}], [\max_i\{z_{i2}^L\}, \max_i\{z_{i2}^U\}], \cdots, [\max_i\{z_{in}^L\}, \max_i\{z_{in}^U\}])$and the negative ideal solution according to $\tilde{z}^- = ([\min_i\{z_{i1}^L\}, \min_i\{z_{i1}^U\}], [\min_i\{z_{i2}^L\}, \min_i\{z_{i2}^U\}], \cdots, [\min_i\{z_{in}^L\}, \min_i\{z_{in}^U\}])$. Then calculate the distance between each scheme and the positive and negative ideal solutions according to formula (1), which are marked as d_i^+ and d_i^- respectively, where $i = 1, 2, \cdots, m$.

Step 7 Calculate the relative closeness degree of the weighted comprehensive attribute value of each scheme according to$c_i = \frac{d_i^-}{d_i^- + d_i^+}$ and sort by the relative closeness degree.

The greater relative closeness degree is, the better the scheme will be.

Step 8 Transforming an interval number into two exact numbers makes the comparison about two numbers easier. But letting α be the unique value will lead to information loss. Thus, the schemes ranking is influenced even inaccuracy.

So, let α be all kinds of possible value and sort the schemes according to the average value of the ranking number of each scheme which includes all the information of the intervals. The smaller the average value of the ranking number is, the better the scheme will be.

3. Case analysis and results

3.1. Case analysis

Consider to buy one from 4 domestically-produced vehicles of the same grade which are noted to be $X_i(i = 1, 2, 3, 4)$. It is necessary to consider 8 aspects including the price (ten thousand yuan /vehicle), fuel consumption (liters/100 km), space (points), power (points), control (points), comfort (points), appearance (points) and interiors (points), which are marked as $S_j(j = 1, 2, \cdots, 8)$ respectively, where $S_j(j = 1, 2)$ is a cost-based type and $S_j(j = 3, \cdots, 8)$ is a profit-based type as well as consumer scores. The initial data are from Autohome which are shown in Table 1.

The left end point and length of each interval number in Table 1 are calculated according to formula (2, 3) to obtain Table 2 and Table 3.

Table 2 and Table 3 are normalized respectively to obtain Table 4 and Table 5 accordingly.

Table 4 and Table 5 are Uniformized to obtain Table 6 and Table 7.

The entropy weight method is adopted to obtain the weight of each index corresponding to Table 6 and Table 7 and the weight vectors are got which are $w1 = (0.227, 0.106, 0.064, 0.105, 0.066, 0.282, 0.073, 0.076)^T$ and $w2 = (0.010, 0.113, 0.158, 0.172, 0.109, 0.138, 0.226, 0.074)^T$. Let $\alpha = 0.6$, the two weight vectors are combined to obtain the vector $w = (0.140, 0.108, 0.102, 0.224, 0.134, 0.075)^T$.

The data in Table 1 is normalized to obtain Table 8.

Calculate the weighted attribute value of each scheme according to formula (4). Obtain he positive ideal solution is $\tilde{z}^+ = ([0.047, 0.113], [0.054, 0.060], [0.049, 0.056], [0.064, 0.073], [0.041, 0.044], [0.110, 0.126], [0.065, 0.073], [0.034, 0.044])$ and the negative ideal solution is $\tilde{z}^- = ([0.043, 0.102], [0.047, 0.055], [0.046, 0.054], [0.059, 0.070], [0.038, 0.043], [0.095, 0.120], [0.060, 0.070], [0.032, 0.041])$.

The distance between each scheme and the positive ideal solution is $d^+ = (0.039, 0.022, 0.034, 0.032)^T$ and the distance between each scheme and the negative ideal solution is

Table 1 Interval number matrix.

	S_1	S_2	S_3	S_4
X_1	[9.80, 15.49]	[6.6, 7.3]	[4.41, 4.96]	[4.24, 4.80]
X_2	[9.98, 13.98]	[6.5, 6.8]	[4.62, 4.74]	[4.47, 4.72]
X_3	[8.98, 13.98]	[6.7, 6.9]	[4.32, 4.85]	[4.28, 4.85]
X_4	[8.98, 14.68]	[7.1, 7.7]	[4.54, 4.72]	[4.60, 4.68]

	S_5	S_6	S_7	S_8
X_1	[4.26, 4.66]	[4.02, 4.48]	[4.52, 4.96]	[4.21, 4.81]
X_2	[4.47, 4.59]	[4.48, 4.67]	[4.62, 4.84]	[4.00, 4.61]
X_3	[4.32, 4.64]	[3.88, 4.64]	[4.35, 4.85]	[3.99, 4.70]
X_4	[4.55, 4.69]	[4.21, 4.43]	[4.68, 4.71]	[4.24, 4.44]

Table 2 Left end point matrix.

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
X_1	9.80	6.6	4.41	4.24	4.26	4.02	4.52	4.21
X_2	9.98	6.5	4.62	4.47	4.47	4.48	4.62	4.00
X_3	8.98	6.7	4.32	4.28	4.32	3.88	4.35	3.99
X_4	8.98	7.1	4.54	4.60	4.55	4.21	4.68	4.24

Table 3 Length matrix.

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
X_1	5.69	0.70	0.55	0.56	0.40	0.46	0.44	0.60
X_2	4.00	0.30	0.12	0.25	0.12	0.19	0.22	0.61
X_3	5.00	0.20	0.53	0.57	0.32	0.76	0.50	0.71
X_4	5.70	0.60	0.18	0.08	0.14	0.22	0.03	0.20

Table 4 Normalized left end point matrix.

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
X_1	0.916	0.985	0.955	0.922	0.936	0.897	0.966	0.993
X_2	0.900	1.000	1.000	0.972	0.982	1.000	0.987	0.943
X_3	1.000	0.970	0.935	0.930	0.949	0.866	0.929	0.941
X_4	1.000	0.915	0.983	1.000	1.000	0.940	1.000	1.000

Table 5 Normalized length matrix.

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
X_1	0.703	0.286	1.000	0.982	1.000	0.605	0.880	0.845
X_2	1.000	0.667	0.218	0.439	0.300	0.250	0.440	0.859
X_3	0.800	1.000	0.964	1.000	0.800	1.000	1.000	1.000
X_4	0.702	0.333	0.327	0.140	0.350	0.289	0.060	0.282

Table 6 Uniformized left end point matrix.

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
X_1	0.240	0.254	0.247	0.241	0.242	0.242	0.249	0.256
X_2	0.236	0.258	0.258	0.254	0.254	0.270	0.254	0.243
X_3	0.262	0.250	0.241	0.243	0.245	0.234	0.239	0.243
X_4	0.262	0.237	0.254	0.262	0.259	0.254	0.258	0.258

Table 7 Uniformized length matrix.

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
X_1	0.219	0.125	0.399	0.384	0.408	0.282	0.370	0.283
X_2	0.312	0.292	0.087	0.171	0.122	0.117	0.185	0.288
X_3	0.250	0.438	0.384	0.390	0.327	0.466	0.420	0.335
X_4	0.219	0.146	0.130	0.055	0.143	0.135	0.025	0.094

Table 8 Normalized interval number matrix.

	S_1	S_2	S_3	S_4
X_1	[0.303, 0.739]	[0.460, 0.542]	[0.458, 0.554]	[0.445, 0.545]
X_2	[0.336, 0.726]	[0.494, 0.550]	[0.479, 0.530]	[0.469, 0.536]
X_3	[0.336, 0.807]	[0.487, 0.534]	[0.448, 0.542]	[0.449, 0.551]
X_4	[0.320, 0.807]	[0.436, 0.503]	[0.471, 0.527]	[0.483, 0.532]

	S_5	S_6	S_7	S_8
X_1	[0.459, 0.529]	[0.441, 0.539]	[0.467, 0.546]	[0.453, 0.585]
X_2	[0.481, 0.521]	[0.492, 0.562]	[0.477, 0.533]	[0.431, 0.561]
X_3	[0.465, 0.527]	[0.426, 0.559]	[0.449, 0.534]	[0.430, 0.572]
X_4	[0.490, 0.533]	[0.462, 0.533]	[0.483, 0.518]	[0.457, 0.540]

$d^- = (0.024, 0.043, 0.034, 0.036)^T$. The relative closeness degree of each scheme $c = (0.381, 0.657, 0.498, 0.532)^T$is obtained. Therefore, the order of each scheme is obtained as$X_2 \succ X_4 \succ X_3 \succ X_1$.The optimal scheme is X_2.

The values of α are changed to get the corresponding scheme ranking, see Table 9.

Based on the data in Table 9, it can be seen that the average rankings of the 4 schemes are 3.73, 1, 3.27, and 2. So the final

Table 9 The ranking order of each scheme in terms of different values of α.

α	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
X_1	3	3	3	4	4	4	4	4	4	4	4
X_2	1	1	1	1	1	1	1	1	1	1	1
X_3	4	4	4	3	3	3	3	3	3	3	3
X_4	2	2	2	2	2	2	2	2	2	2	2

Table 10 Ranking order of alternatives using different values ofα.

α	X_1	X_2	X_3	X_4	Ranking order
0	0.469	0.713	0.399	0.481	$X_2 \succ X_4 \succ X_1 \succ X_3$
0.1	0.453	0.702	0.417	0.490	$X_2 \succ X_4 \succ X_1 \succ X_3$
0.2	0.437	0.692	0.435	0.499	$X_2 \succ X_4 \succ X_1 \succ X_3$
0.3	0.422	0.683	0.452	0.508	$X_2 \succ X_4 \succ X_3 \succ X_1$
0.4	0.408	0.674	0.468	0.516	$X_2 \succ X_4 \succ X_3 \succ X_1$
0.5	0.394	0.665	0.483	0.524	$X_2 \succ X_4 \succ X_3 \succ X_1$
0.6	0.381	0.657	0.498	0.532	$X_2 \succ X_4 \succ X_3 \succ X_1$
0.7	0.368	0.650	0.512	0.539	$X_2 \succ X_4 \succ X_3 \succ X_1$
0.8	0.355	0.643	0.526	0.546	$X_2 \succ X_4 \succ X_3 \succ X_1$
0.9	0.343	0.636	0.539	0.553	$X_2 \succ X_4 \succ X_3 \succ X_1$
1	0.332	0.629	0.551	0.560	$X_2 \succ X_4 \succ X_3 \succ X_1$

ranking of these 4 schemes is$X_2 \succ X_4 \succ X_3 \succ X_1$and the optimal scheme is X_2. Namely, the 2nd vehicle is the best choice.

3.2. Comparative analysis

In this section, we make two comparative analyses.

The first is to analyze effects of parameter α on decision-making results with interval numbers given in Table 1.

By using different values of parameter α, it effects the ranking order results. The results are shown in Table 10. At the meanwhile, the relative closeness degrees are given in Fig. 1.

The second is to compare our method with the presented method by Sun A M [6]. The interval numbers are given in [6]. A comparison between the results of the proposed method and the results of the other method is shown in Table 11.

From Table 11, we find the ranking order is identical and the optimal solution is X_4. The results show our proposed method is reliable. That is, we proposed a new effective method for interval number multi-attribute decision-making problems whose attribute weights are unknown.

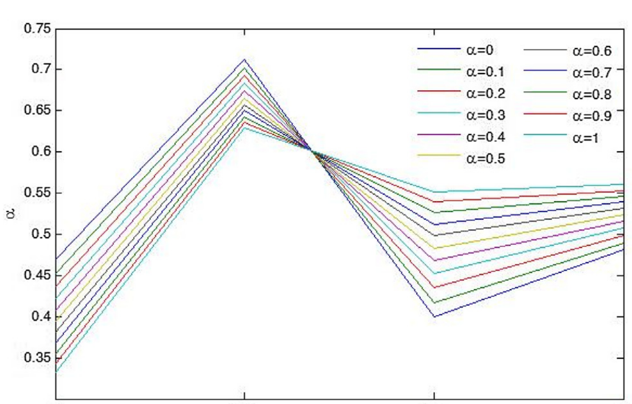

Fig. 1 The relative closeness degrees.

Table 11 Ranks of alternatives of proposed methods.

Method	Ranking order
The proposed method	$X_4 \succ X_2 \succ X_3 \succ X_1$
The method in Ref. [6]	$X_4 \succ X_2 \succ X_3 \succ X_1$

4. Conclusion and promotion

It is difficult to compare the value of two intervals. In this paper, a novel method is proposed to solve multi-attribute decision-making problems with interval numbers. Two types of exact numbers which are left end point and length are used to replace an interval number which facilitates the determination of attribute weights. At the same time, when determining weights, a variety of possible rankings are considered, and the information brought by interval numbers is fully utilized to ensure the accuracy of results.

When extracting exact numbers from interval numbers, other methods can also be applied, that is, interval numbers can be replaced with the right end point and length, or the left end point and the midpoint, or the right end point and the midpoint. And the other steps are the same as the corresponding content in this paper. All of them can reduce the difficulty of the problem, and the optimal solution obtained is the same as the method presented in this paper.

Finally, the feasibility and effectiveness of the proposed method have been demonstrated by car purchasing. The method can also be used to solve the group decision-making problems with intervals.

Through above analysis, we can conclude our proposed method gets the same results with the existing method in [6].

And we get the same optimal solution with the method in [10] while the ranking order is not identical. As a future work, we can perform sensitivity analysis of α. Additionally, we plan to solve the group decision-making problems with intervals.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Y. Sui, J. Hu, F. Ma, A mean-variance portfolio selection model with interval-valued possibility measures, Math. Probl. Eng. 2020 (2020) 1–12, https://doi.org/10.1155/2020/4135740.
[2] Z.W. Li, Study on Methods for Multiple Attribute Decision Making Under Inter Decision Making Under Interval Uncertainty, Southwest Jiaotong University, 2010, Master Degree Thesis.
[3] D.Q. Li, W.Y. Zeng, Q. Yin, Ranking interval numbers: a review, J. Beijing Normal Univ. (Natl. Sci.) 56 (4) (2020) 483–492, https://doi.org/10.12202/j.0476-0301.2019155.
[4] N. Yao, Y. Ye, Q. Wang, N. Hu, Interval number ranking method considering multiple decision attitudes, Iran. J. Fuzzy Syst. 17 (2) (2020) 115–127.
[5] M.A. Firozja, G.H. Fath-Tabar, Z. Eslampia, The similarity measure of generalized fuzzy numbers based on interval distance, Appl. Math. Lett. 25 (10) (2012) 1528–1534, https://doi.org/10.1016/j.aml.2012.01.009.
[6] A.M. Sun, Interval number multiple index decision making method based on entropy weight method and its application, Math. Pract. Theory 4 (2020) 171–179.
[7] P. Chen, Effects of the entropy weight on TOPSIS, Expert Syst. Appl. 168 (2021) 114186, https://doi.org/10.1016/j.eswa.2020.114186.
[8] P.Y. Dong, H.W. Wang, Y. Chen, Combining TOPSIS and GRA for emitter threat evaluation with interval numbers, Control Decis. 5 (2020) 1–7.
[9] Z. Yue, An extended TOPSIS for determining weights of decision makers with interval numbers, Knowl.-Based Syst. 24 (1) (2011) 146–153, https://doi.org/10.1016/j.apm.2010.11.001.
[10] L.Y. Wang, Y.C. Cao, L.M. Su, H.M. Li, R.S. Zhao, Interval Multi-attribute decision making method with unknown attribute weights, Math. Practice Theory 49 (14) (2019) 298–304.
[11] M. Zhang, G.-x. Li, Combining TOPSIS and GRA for supplier selection problem with interval numbers, J. Central South Univ. 25 (5) (2018) 1116–1128, https://doi.org/10.1007/s11771-018-3811-y.
[12] K.J. Chen, P. Chen, Decision making method of TOPSIS based on three-parameter interval grey numbers, Syst. Eng. Electron. 41 (1) (2019) 124–130, https://doi.org/10.3969/j.issn.1001-506X.2019.01.18.
[13] Y.Z. Mehrjerdi, Developing fuzzy TOPSIS method based on interval valued fuzzy sets, Int. J. Comput. Appl. 42 (14) (2012) 7–18, https://doi.org/10.5120/5758-7891.
[14] B. Luo, Y. Ye, N. Yao, Q. Wang, Interval number ranking method based on multiple decision attitudes and its application in decision making, Soft. Comput. 25 (5) (2021) 4091–4101, https://doi.org/10.1007/s00500-020-05434-1.
[15] S. Qu, Y. Xu, Z. Wu, Z. Xu, Y. Ji, D. Qu, Y. Han, An Interval-Valued Best-Worst method with normal distribution for multi-criteria decision-making, Arab. J. Sci. Eng. 46 (2) (2021) 1771–1785, https://doi.org/10.1007/s13369-020-05035-.
[16] D. Ding, H.H. Huang, A graph attention based approach for trajectory prediction in multi-agent sports games. arXiv preprint arXiv:2012.10531, 2020.
[17] S. Ghobadi, Merging decision-making units with interval data, RAIRO-Operat. Res. 55 (2021) S1605–S1631, https://doi.org/10.1051/ro/2020029.
[18] Y.T. İç, A TOPSIS based design of experiment approach to assess company ranking, Appl. Math. Comput. 227 (2014) 630–647, https://doi.org/10.1016/j.amc.2013.11.043.
[19] R.M. Zulqarnain, X.L. Xin, M. Saqlain, W.A. Khan, F. Feng, TOPSIS Method based on the correlation coefficient of interval-valued intuitionistic fuzzy soft sets and aggregation operators with their application in decision-making, J. Math. 2021 (2021) 1–16, https://doi.org/10.1155/2021/6656858.
[20] C.M. Acuña-Soto, V. Liern, B. Pérez-Gladish, Multiple Criteria performance evaluation of YouTube mathematical educational videos by IS-TOPSIS, Oper. Res. Int. J. (2018) 1–23, https://doi.org/10.1007/s12351-018-0405-.
[21] C.L. Hwang, K. Yoon, Multiple Attribute Decision Making and Applications, Springer-Verlag, New York, 1981.