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OPTIMIZATION OF PHYSICAL INSTRUMENTS' CHARACTERISTICS WITH TOPSIS

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Abstract. The present study focuses on the characteristics optimization of the physical instruments with the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The hypothesis in this research work was that the characteristics of spectrometers and rheometers could affect their rankings, which in turn could be influenced by the underestimation of their cost criterion. In this paper, the characteristics optimization of the FTIR spectrometers and rheometers was carried out with TOPSIS. Moreover, its modified algorithm was also used in order to analyze the inappropriate consideration of these instruments due to category confusion. The modification of TOPSIS helped obtain an automated decision-making method for the treatment of data. The results showed that the rankings of the FTIR spectrometers and rheometers were different as expected. Moreover, the rankings of the FTIR spectrometers were different with using the unmodified and modified TOPSIS; however, that of the rheometers did not change. The change in the ranking of the FTIR spectrometers was due to the application of the fuzzy disjunction in the TOPSIS code. In this case, the first and second candidates were placed in the first and second positions, respectively, whereas the second candidate had a better rank than the first one in the analysis with the unmodified TOPSIS code. The rank improvement of the first candidate in the category of FTIR spectrometers after the modification of the TOPSIS code was also observed. The results of this work can be used in mechanical engineering and materials science as the appropriate use of instruments in these fields depends on the consideration of their characteristics for which their optimization in comparison with those of other instruments could provide interesting results. Such investigations would provide complementary data for the experimental approaches in further applications.

Keywords: FTIR spectrometer, rheometer, mechanical engineering, materials science, TOPSIS, automated decision-making.

Introduction and Problem Statement

Spectrometers and rheometers are used for investigations on the properties of materials in materials sciences and mechanical engineering. These are important equipments for which the improvement of characteristics influences the research work results [1–5].

Fourier transform infrared (FTIR) spectrometers are the instruments used for the analysis of the chemical composition of diverse materials such as nanomaterials, polymers, biological materials, etc. [6–8]. The samples that are energy-limited or when increased speed of data acquisition, sensitivity and resolution are required for their analysis are othen analyzed with these equipments [9].

Different types of these instruments such as attenuated total reflectance (ATR) spectrometers, FTIR photoacoustics spectrometers, FTIR spectrometers equipped with a microscope are used in the labs [10–12]. Rheometers are the instruments used for the measurement of the deformation resistance of materials or their flow [13, 14]. Two types of rheometers such as stress-controlled and strain-controlled rheometers are used for the rheological investigation of materials [15, 16].

During several decades, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) has been used for the characteristics optimization and the ranking of materials [17–21]. This method has also been used for the ranking of instruments and devices [22–24].

The application of TOPSIS with an automated decision-making process for the optimization of the instruments used in mechanical engineering and materials science could improve the research works in these fields. FTIR spectrometers and rheometers with diverse applications have been appropriate candidates for this investigation. The aim of this research work was to perform this analysis and illustrate the results for further studies.

Several automated decision-making processes have been proposed for the improvement of this algorithm, previously. However, none of them has been applied for the analysis of the category confusion. In this paper, a recently developped vesion of this method for performing the modifications on the columns and rows of this algorithm has been applied for this purpose [25].

The characteristics optimization of FTIR spectrometers and rheometers has not been performed with TOPSIS, yet. The results of this paper can be used to improve the investigations on these physical instruments as well as the optimization of their consideration for the design and experimentation in the labs.

Main Material Presentation

For the analysis of the different types of FTIR spectrometers and rheometers, the candidates were considered as follows. In the first series of analysis, Three members of the category of FTIR spectrometers such as an ATR-FTIR spectrometer, a FTIR photoacoustics spectrometer and a FTIR spectrometer equipped with a microscpe were the first, second and third candidates (C_1 , C_2 and C_3), respectively. In the second series of analysis, three members of the category of rheometers such as two stress-controlled rheometers and a strain-controlled rheometer were considered as the first, second and third candidates (C_1, C_2 and C_3), respectively. The triangular fuzzy membership degrees of the candidates were 0.8, 0.9, 1.0 for high level, 0.4, 0.5, 0.6 for medium level and 0.1, 0.2, 0.3 for low level, respectively. The mean values of these degress were 0.9, 0.5 and 0.2, respectively.

TOPSIS method

The Python code of TOPSIS developed by Chakravorty (https://github.com/Glitchfix/TOPSIS-Python/blob/master/topsis.py), was used in the current work for the characteristics optimization of the FTIR spectrometers and rheometers. The steps of the TOPSIS method were described previously [25]. Positive characteristics of these instruments were as below: function, measurement accuracy and rigidity. These were considered as profit criteria in the TOPSIS method. Price was considered as a negative characteristic or cost criterion.

In another series of analysis, a previously developed model, the model of tree [26], was used for the determination of category confusion due to the individuals' inappropriate consideration of large instruments and inconsistency in their epistemic beliefs [27]. It would be preferable to have instruments as small as possible in the labs in order to have enough place for other instruments. Therefore, size was considered as a profit criterion whereas in an appropriate consideration, it would be a cost criterion. This individuals' underestimation was evaluated in the second series of analysis in this paper.

Modification of TOPSIS

The modification in the TOPSIS code was performed for constructing software and resolving problems with automated decision-making process as described previously. For this purpose, the Łukasiewicz fuzzy disjunction was used in the modified TOPSIS in order to analyze the inconsistency of epistemic beliefs and determine the candidates' values of the membership degrees [26]. The difference was that in the modified TOPSIS code for the current paper, the modification with the the Łukasiewicz fuzzy disjunction was considered for the last column and last two rows of the matrices including the entry data for the FTIR spectrometers and rheometers.

Results and Discussion

Tables 1 and 2 show the entry data including the terms, triangular fuzzy membership degrees of candidates' characteristics and their mean values for FTIR spectrometers and rheometers, respectively.

The difference in the values in these tables concern the second and fourth criteria as the attributed values for the measurement accuracy of candidate 2 in Table 1 are 0.4, 0.5, 0.6, whereas they change to 0.1, 0.2, 0.3 for the same criterion in Table 2. The attributed values for the price of candidate 2 in Table 1 are 0.4, 0.5, 0.6, whereas they change to 0.8, 0.9, 1.0 for the same criterion in Table 2.

Table 1

Terms, triangular fuzzy membership degrees of candidates' characteristics and their mean values for FTIR spectrometers

Candidates/Criteria	Function	Measurement accuracy	Rigidity	Price
C_1	high	medium	low	high
C_2	medium	medium	medium	medium
C_3	low	low	high	medium

Candidates/Criteria	Function	Measurement accuracy	Rigidity	Price
C_1	0.8, 0.9, 1.0	0.4, 0.5, 0.6	0.1, 0.2, 0.3	0.8, 0.9, 1.0
C_2	0.4, 0.5, 0.6	0.4, 0.5, 0.6	0.4, 0.5, 0.6	0.4, 0.5, 0.6
C_3	0.1, 0.2, 0.3	0.1, 0.2, 0.3	0.8, 0.9, 1.0	0.4, 0.5, 0.6

Candidates/Criteria	Function	Measurement accuracy	Rigidity	Price
C_1	0.9	0.5	0.2	0.9
C_2	0.5	0.5	0.5	0.5
C_3	0.2	0.2	0.9	0.5

Table 2

Terms, triangular fuzzy membership degrees of candidates' characteristics and their mean values for rheometers

Candidates/Criteria	Function	Measurement accuracy	Rigidity	Price
C_1	high	medium	low	high
C_2	medium	low	medium	high
C_3	Low	low	high	medium

Candidates/Criteria	Function	Measurement accuracy	Rigidity	Price
C_1	0.8, 0.9, 1.0	0.4, 0.5, 0.6	0.1, 0.2, 0.3	0.8, 0.9, 1.0
C_2	0.4, 0.5, 0.6	0.1, 0.2, 0.3	0.4, 0.5, 0.6	0.8, 0.9, 1.0
C_3	0.1, 0.2, 0.3	0.1, 0.2, 0.3	0.8, 0.9, 1.0	0.4, 0.5, 0.6

Candidates/Criteria	Function	Measurement accuracy	Rigidity	Price
C_1	0.9	0.5	0.2	0.9
C_2	0.5	0.2	0.5	0.9
C_3	0.2	0.2	0.9	0.5

Table 3 shows the weights applied for each criterion of both instruments.

Table 3

Weights applied for each criterion of both instruments

Alternatives/Values	Function	Measurement accuracy	Rigidity	Price
C_1-C_3	0.5	0.5	0.5	0.5

Table 4 shows the criteria matrix for both instruments indicating True for the profit criteria and false for the cost criterion, respectively.

Table 4

Criteria matrix for both instruments

Alternatives/Values	Function	Measurement accuracy	Rigidity	Price
C_1-C_3	True	True	True	False

The results of the normalized decision matrices and weighted normalized decision matrices of both instruments are shown in Tables 5 and 6, respectively.

Table 5

The normalized decision matrix for FTIR spectrometers

Candidates/Criteria	Function	Measurement accuracy	Rigidity	Price
C_1	0.85811633	0.68041382	0.19069252	0.78633365
C_2	0.47673129	0.68041382	0.47673129	0.43685203
C_3	0.19069252	0.27216553	0.85818633	0.43685203

The weighted normalized decision matrix for FTIR spectrometers

Candidates/Criteria	Function	Measurement accuracy	Rigidity	Price
C_1	0.21452908	0.17010345	0.04767313	0.19658341
C_2	0.11918282	0.17010345	0.11918282	0.10921301
C_3	0.04767313	0.06804138	0.21452908	0.10921301

Table 6

The normalized decision matrix for rheometers

Candidates/Criteria	Function	Measurement accuracy	Rigidity	Price
C_1	0.85811633	0.87938828	0.19069252	0.65814518
C_2	0.47673129	0.34815531	0.47673129	0.65814518
C_3	0.19069252	0.34815531	0.85818633	0.36563621

The weighted normalized decision matrix for rheometers

Candidates/Criteria	Function	Measurement accuracy	Rigidity	Price
C_1	0.21452908	0.21759707	0.04767313	0.16453630
C_2	0.11918282	0.08703883	0.11918282	0.16453630
C_3	0.04767313	0.08703883	0.21452908	0.09140905

The best alternative (A^+) and the worst alternative (A^-) for the FTIR spectrometers and rheometers are presented in Tables 7 and 8, respectively.

Table 7

The best alternative and the worst alternative for FTIR spectrometers

Candidates/Criteria	Function	Measurement accuracy	Rigidity	Price
A^+	0.21452908	0.17010345	0.21452908	0.10921301
A^-	0.04767313	0.06804138	0.04767313	0.19658341

Table 8

The best alternative and the worst alternative for rheometers

Candidates/Criteria	Function	Measurement accuracy	Rigidity	Price
A^+	0.21452908	0.21759707	0.21452908	0.09140905
A^-	0.04767313	0.08703883	0.04767313	0.16453630

The results of the distances from the best alternative and the worst alternative for the FTIR spectrometers and rheometers are shown in Tables 9 and 10, respectively.

Table 9

The distances from the best alternative and the worst alternative for FTIR spectrometers

Candidates/Criteria	The best alternative	The worst alternative
C_1	0.18834675	0.19559544
C_2	0.13483997	0.16815923
C_3	0.19559544	0.18834675

Table 10

The distances from the best alternative and the worst alternative for rheometers

Candidates/Criteria	The best alternative	The worst alternative
C_1	0.18217712	0.21186402
C_2	0.20143204	0.10112998
C_3	0.21186402	0.18217712

Tables 11 and 12 show the closeness coefficients (*CCi*) and the rankings of FTIR spectrometers and rheometers, respectively.

Table 11

The closeness coefficients and the ranking of FTIR spectrometers according to the worst similarity

Candidates/Criteria	CC_i	Ranking
C_1	0.50943982	2
C_2	0.55498242	1
C_3	0.49056018	3

Table 12

The closeness coefficients and the ranking of rheometers according to the worst similarity

Candidares/Criteria	CC_i	Ranking
C_1	0.53766980	1
C_2	0.33424545	3
C_3	0.46233202	2

The results in Tables 11 and 12 showed that the rankings of FTIR spectrometers and rheometers were different as expected. It was interesting to investigate the impact of the modification of TOPSIS on the ranking of both categories.

The second series of analysis was performed with the modified TOPSIS and the results presented below were obtained.

Tables 13 and 14 show the entry data for the FTIR spectrometers and rheometers, respectively.

Table 13

The mean values of triangular fuzzy degrees of FTIR spectrometers

Candidates/Criteria	Function	Measurement accuracy	Rigidity	Size
C_1	0.9	0.5	0.2	0.9
C_2	0.5	0.5	0.5	1.0
C_3	0.2	0.2	0.9	1.0

Table 14

The mean values of triangular fuzzy degrees of rheometers

Candidates/Criteria	Function	Measurement accuracy	Rigidity	Size
C_1	0.9	0.5	0.2	0.9
C_2	0.5	0.2	0.5	1.0
C_3	0.2	0.2	0.9	1.0

The value of 1.0 was appeared in the output of TOPSIS in the last column and two last rows of both of these matrices.

Tables 15 and 16 show the closeness coefficients (*CCi*) and the rankings of the FTIR spectrometers and rheometers, respectively.

Table 15

The closeness coefficients and the ranking of FTIR spectrometers according to the worst similarity

Candidates/Criteria	CC_i	Ranking
C_1	0.53865743	1
C_2	0.51720772	2
C_3	0.46134257	3

Table 16

The closeness coefficients and the ranking of rheometers according to the worst similarity

Candidates/Criteria	CC_i	Ranking
C_1	0.55844047	1
C_2	0.35260138	3
C_3	0.44155953	2

The comparison of results in Tables 11, 12, 15 and 16 revealed that the rankings of the FTIR spectrometers were different with the unmodified and modified TOPSIS, however that of the rheometers did not change. The change in the ranking of the FTIR spectrometers was due to the fact that after applying the Łukasiewicz fuzzy disjunction in the TOPSIS code, the first and second candidates were placed in the first and second positions, respectively, whereas the second candidate had a better rank than the first one when the unmodified TOPSIS code was used. The rank improvement of the first candidate in the category of FTIR spectrometers after the modification of the TOPSIS code was because of the application of this disjunction for the second and third candidates. In other words, the first candidate was not affected with this disjunction and it could have an improved rank when the modified algorithm was used.

The optimization of the manufacturing processes has been performed with TOPSIS [28–[31] and the application of the fuzzy disjunction operator in this algorithm can help explain the confusion of categories. Other aspects of fuzzy logic such as conjunction operator and implication operator applied on the decision makers can be improved [32–36]. The implementation of these operators in the TOPSIS code can help perform investigations in other situations affected by the optimization of physcial instruments' characteristics [37–43]. The analysis of these instruments with TOPSIS requires more investigation in the future.

Conclusions

It is often assumed that the individuals have appropriate consideration of the candidates when the unmodified TOPSIS method is used for optimization. However, the underestimation of the impact of the cost criteria on the comparison of candidates with the other category members can influence the outputs. The FTIR spectrometers and rheometers have been investigated in this work. The results showed that the rankings of these instruments depended on their fuzzy membership degrees. Moreover, the modification of the TOPSIS code changed the ranking of the first category of instruments, whereas that of the second category did not change. The application of this type of analysis for other instruments in a comparable investigation can help investigate their optimization for the improvement of their quality for research works in mechanical engineering and materials science.

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