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Ordering of innovation projects by multi-criteria decision-making methods – a comparison

Introduction

Social and economic inequalities exist objectively. In the case of the integration process, economic and social differences between economic units represent a barrier. There are reasonable and active efforts of many administrative bodies to transfer existing inequalities to equalities. That is why the European Union also pays special attention to economic and social cohesion in its regional policy. Due to the changing conditions, the principles of this policy have been continuously innovated for individual periods. For the years 2014 to 2020, four principles have been identified for cohesion policy: concentration (resources, efforts, and expenditure), programming, partnership, and complementarity (European Commission, 2014).

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Using innovative projects to support step-by step development in a certain area of industry, region or society can be seen as a practical step to the principles mentioned above. Preparation of calls for the projects is an inevitable step to the process as well as the next technical step related to selection of the most suitable projects. As a result, a decision maker (DM) can obtain an order of the projects according to their quality.

Different approaches and methods are used for decision making in these cases. From a wide range of possible methods, it is necessary to choose suitable ones. Even in this case, a condition may occur in which several suitable methods are available. It is therefore necessary to determine whether the results of using these methods are similar or different. It is while adhering to the first principle that the use of multi-criteria decision-making (MCDM) methods can be beneficial.

It is illusory to assume that it is possible to evaluate the similarity and difference of the results of all decision-making methods. M. Kumru and P. Y. Kumru (2014) admit that different methods may yield different results for the same problem. The choice of which method/model is the most appropriate depends on the problem at hand and may be to some extent dependent on which model the DM is the most comfortable with. The most frequently used by them are TOPSIS, ELECTRE, PROMETHEE, MACBETH, and AHP.

In this paper, we focus only on MCDM methods, specifically on these ordering methods: Analytical Hierarchy Process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and Weighted Linear Combination (WLC). The goal of the paper is evaluation of a similarity and difference of the results on a basic set of innovative projects.

Methods of multi-criteria analysis

To evaluate and select innovative projects (IP) with different criteria, several authors recommend the use of MCDM. E.g., A. Neves and R. Camanho (2015) focused in their study on the application of the AHP method in solving the problem of prioritising investment opportunities in IT projects. The conclusion of their study is a positive evaluation of the AHP method and recommendations for the addition of several criteria or use of other MCDM methods and their comparison.

A. Cubukcu (2018) argues that the most difficult part of evaluating investment opportunities and IP is the phase of selecting the best alternative/s for IP by evaluating these projects. This study offers a multi-criteria approach. The author states that a given approach is chosen for the reason that this approach excludes mainly alternatives that have lower scores related to the dominant or most important acceptance criteria. The author uses the TOPSIS and WLC methods and recommends the use of these methods in decision-making based on several criteria.

C. Macharis and A. Bernardini (2015) focus their research on the use of multi-criteria analysis to evaluate innovative projects in the automotive industry. The aim of their study is to point out the increasing use of decision analysis methods in the evaluation and selection of projects. The authors point out the suitability of the methods and give an overview as well as the way of their use.

In recent decades, several criteria have been proposed to evaluate the success of a project. As in the evaluation of innovation processes, there is no uniform methodology for evaluation of IPs. This is because the criteria for the success of an IP may differ between different types of projects and depending on their objectives.

All evaluated methods of multi-criteria analysis provide the possibility to determine the score of each evaluated object according to the selected criteria. For evaluation, it is necessary for the selected criteria to be the same for all evaluated methods. Each of the evaluated methods in the article contains the same basic steps: criteria selection, setting of weights (suitable for the selected method), and results (scores + order).

The procedure for selecting appropriate object evaluation criteria is determined by the evaluator (i.e. DM), and criteria can be selected according to qualitative (individual, political) or quantitative procedures (e.g. using correlations). In the case of regional disparities, regions can have their own common criteria concerning the level of development, and they can be set by political decisions.

Again, subjectively (e.g., the ranking method) or objectively (e.g. Saaty's method), weights obtained can be used to determine the weights of the selected criteria. For practicality and simplicity, the ranking method for the WLC and TOPSIS methods is used in our evaluation. When using it, the DM ranks the criteria from the most important to the less important. In the case of the AHP method, Saaty's matrix is used as T. Saaty (1980) himself is the creator of the AHP method. The method is based on compiling Saaty's matrix of pairwise comparisons. Within it, the DM determines which of the two criteria being compared is more important, and determines the degree of preference.

Using the evaluated methods, we obtain certain scores of objects according to the selected criteria. The evaluated objects with their obtained scores can be sorted and thus create the order of fulfilment of the several criteria selected (multi-criteria analysis).

Parallel evaluation of the investigated methods using real data is rare. It is possible to find their sequential use (e.g. AHP → WLC by J. Blachowski (2015); A. El Jazouli *et al.* (2019)) in creating order as a basis for decision making. Sequential use of the AHP, TOPSIS and WLC methods is provided by e.g. Al Garni and A. Awasthi (2018).

E.A. Santana (1996) has conducted a comparative study on the AHP, ELECTRE, and TOPSIS methods and considered that AHP is more robust than the other two. TOPSIS was considered the simpler of the studied methods. S.H. Zanakis *et* *al.* (1996) performed comparisons on AHP, ELECTRE, TOPSIS and two more methods, using simulated data. The results obtained by the AHP and TOPSIS methods showed some similarity. However, the results from TOPSIS and ELECTRE presented significant divergence. J. Zak (2005) in his study based on the opinions of DMs and stakeholders who applied the methods draws, relevant to this paper, conclusions that (i) the methods have a universal character and can be applied with satisfactory computational efficiency to multi-objective ranking problems; (ii) the AHP method is the most reliable and MCDM is the most user friendly; and (iii) the AHP method can be applied for decision problems with a smaller as well as larger number of variants.

It is possible to find many descriptions with formulas of different MCDM methods. We can mention D. Anderson *et al.* (2016), J. Blachowski (2015) or G. Beroggi (1999).

Procedure of the AHP method

The importance of the criteria is expressed by pairwise quantitative comparison. The magnitude of the preferences of the i-th criterion over the j-th one is arranged in Saaty's matrix S, where its elements s_{ij} represent estimates of the proportion of the weights of the criteria. The weights of the criteria are then the geometric means of the rows normalised to a scale of 0 to 1. Their calculation as well as another procedure and formulas for the AHP method are given by the authors mentioned above.

Procedure of the TOPSIS method

It was originally created by Hwang and Yoon (1981). The importance of criteria is expressed by assigning the weight of individual criteria, in our case using the ranking method. The number of points is then converted to standard weights and the positive-ideal and negative-ideal solutions are calculated. Subsequently, ranked are distances of each alternative to these solutions, and the relative closeness to the ideal solution. Their calculation as well as another procedure and formulas for the TOPSIS method are given by the authors mentioned above.

Procedure of the WLC method

The WLC method is a variant of the Ordered Weighted Averaging (OWA) method, sometimes sorted as a hybrid between qualitative and quantitative methods. The importance of the criteria is expressed by assigning the weight of the individual criteria, in our case using the ranking method. The number of points is then converted to standard weights and the standard value of the object is gradually expressed. Their calculation as well as another procedure for the WLC method are given by the authors mentioned above.

Methodology

The similarity and difference of the results of the examined methods is evaluated in the paper on a basic sample of 789 innovative projects submitted by companies requesting non-repayable funds (NFP) from the Ministry of Economy of the Slovak Republic (MH SR), and projects which received funds. Data about fund receivers obtained from MH SR, annual reports of individual companies, the Finstat database, and the Central Project Register serve as a basis for criteria selection to evaluate the success of projects and companies. Financial data (e.g. changes in sales) are used at constant prices. This data serves as a basic set of analyses.

Correlation analysis was applied to the selected criteria and thus interdependent criteria were excluded. After excluding the dependent criteria, an analysis of companies and their innovative projects was performed, and their order was determined according to the examined methods. Correlation analysis was also used to compare the results (order) obtained by the AHP, TOPSIS and WLC methods. R and MS-Excel were used for data processing.

Results of the comparison

To assess the substitutability of the investigated methods, the following criteria were available:

1. The given amount contracted from NFP.
2. The amount of NFP spent.
3. Changes in sales after and before the end of the project.
4. The actual number of employees in the company at the year of projects starting.
5. Project duration in months.

The results of cross-correlation of criteria are shown in Table 1. The correlations found a high dependence between the given and spent funds (i.e. what was allocated was also spent) and therefore only 4 criteria were used in the next comparison.

Table 1. Results of cross-correlation of criteria

Correlation index	Financial resources (€)		Change of incomes	Number of employees	Length of project (months)
	given	spent			
Financial resources given (€)	1	0.9987	0.2216	0.2623	0.3962
Financial resources spent (€)		1	0.2226	0.2624	0.3944
Change of incomes			1	0.3170	0.1856
Number of employees				1	0.1227
Length of project (months)					1

Source: authors.

Application of the AHP method

The importance of the criteria in the AHP method is expressed by pairwise quantitative comparison and arranged in Saaty's matrix S, where its elements s_{ij} represent estimates of the proportion of the weights of the criteria, i.e. how many times one criterion is more significant than the other.

The elements of the square matrix on the other side of the diagonal are the inverse values of the elements on the initial side. In the given example (Table 2), if the amount of spent funds as compared to the number of employees in the company in the first line is assigned a value of 7, then, the value will be 1/7 or 0.14 on the opposite side of the matrix diagonal. The weights of the criteria are then the geometric means of the rows. Geometric means are normalised to a scale of 0–1 (w_j).

Table 2. Saaty's matrix and criterion weights

	Financial resources spent (€)	Change of incomes	Number of employees	Length of project (months)	Geometric mean	w_j
Financial resources spent (€)	1.00	0.20	7.00	5.00	1.627	0.245
Change of incomes	5.00	1.00	9.00	7.00	4.213	0.633
Number of employees	0.14	0.11	1.00	0.33	0.270	0.041
Length of project (months)	0.20	0.14	3.00	1.00	0.541	0.081

Source: authors.

For each project, the normalised value is then calculated, taking into account the logical assumption that the project costs should be as low as possible and therefore the cost criterion has the opposite value (high costs have low values and vice versa). Subsequently, the sum of coefficients and scores of each project is calculated. The calculated score determines the order/position of the company/project.

Application of the TOPSIS method

The importance of individual criteria is determined by the ranking method. A value from 1 to 4 is assigned to each criterion; a higher value means higher importance. Subsequently, the standard weights are determined as follows:

1. Amount of spent NFP = 0.30.
2. Change in sales after and before the end of the project = 0.40.
3. The number of employees in the company as of the project start period/year = 0.10.
4. Project duration in months = 0.20.

In the next step, the normalised value of each project is calculated, considering the logical assumption that the project costs should be as low as possible, and therefore the cost criterion has the opposite value (high costs have low values and vice versa). Subsequently, matrix Z is calculated and the positive-ideal and negative-ideal variant for each criterion is found. The ideal variant is the one with the highest normalised value of the criterion, the negative variant is the one with the lowest normalised value of the criterion.

Subsequently, the distance of each project from both variants and the relative distance of each alternative to these solutions are calculated. In the last step, the total score is calculated. The calculated score determines the order/position of the company/project.

Application of the WLC method

The importance of the individual criteria is determined by the ranking method. A value from 1 to 4 is assigned to each criterion; a higher value means higher importance. Subsequently, the standard weights are determined as follows:

1. The amount of spent NFP = 0.30.
2. Change in sales after and before the end of the project = 0.40.
3. The number of employees in the company as of the project start period / year = 0.10.
4. Project duration in months = 0.20.

In the next step, the normalised value of each project is calculated, taking into account the logical assumption that the project costs should be as low as possible and therefore the cost criterion has the opposite value (high costs have low values and vice versa). Subsequently, the total performance value is determined. The calculation is based on standardised project weights and standardised weights of individual criteria. The calculated score determines the order/position of the company/project.

Results of the comparisons

By applying the MCDM methods (AHP, TOPSIS, WLC), we autonomously calculated the order of companies/projects according to suitability based on the specified criteria in each of the methods. The next step was to compare the orders obtained. The aim of the comparison was to determine the degree of matching between the results. The comparison was performed using the Spearman's rank correlation coefficient (or Spearman's ρt) with results represented on the Table 3.

Table 3. Correlations among the ranks

Correlation coefficient	WLC	AHP	TOPSIS
WLC	1.000	0.886	0.285
AHP		1.000	0.378
TOPSIS			1.000

Source: authors.

From the results of the Spearman's rank correlation coefficient, we can see that the WLC and AHP methods produce similar results. The TOPSIS method has more varied results. We can assume that the results depend on the individual methods, because the correlation coefficient showed that:

– the results of the WLC method and the TOPSIS method have $r = 0.285$, which indicates a very low or no correlation respectively,
– $r = 0.378$ between the results of the AHP and TOPSIS methods, which also indicates a weak dependence,
– strong dependence, or a high correlation respectively, is found between the results of the AHP and WLC methods only, where $r = 0.886$.

Conclusions

Three widely used quantitative methods of multi-criteria analysis – AHP, TOPSIS and WLC – are compared. The created order of objects from the basic set of less than 800 objects is compared. The file used is large enough to generalise the results obtained.

We expected that there would be some variations in the order of the ordered objects, but these would not be significant; and the correlation test between them would show a strong dependence. The Spearman's rank correlation coefficient was used for mutual comparison. However, the test results showed that the investigated methods do not provide results with a close dependence, which means that the order of objects created depends on the method used. The results show that it is not appropriate to generalise the results obtained by S.H. Zanakis *et al.* (1998) on the AHP and TOPSIS methods and their similarity. Strong dependence was shown only between the AHP and WLC methods in the presented case. This means that the choice of method for determining the order of objects cannot be selected randomly but requires a more detailed analysis and setting of more precise criteria.

As has been mentioned, the number of criteria is open to the DM; so, it is possible to have criteria which describe development of an area. The areas then can be ordered by the MCDM methods, too.

According to the choice of an MCDM method we can see one more issue related to social disparities: transparency of IP ordering because of public funds. As has been mentioned above, the ordering depends on the method chosen by a DM. Thus, it is inevitable in the time of making calls for the projects to announce not only the criteria for ordering, but also the method used for ordering. It can avoid suspicions of manipulation during the ordering process.

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Summary

In the case of the integration process, economic and social differences between economic units represent a barrier. There are reasonable and active efforts of many administrative bodies to transfer the existing inequalities to equalities. In practical life, it is often necessary to order different objects and take a decision based on it. Decision-making can be intuitive or, conversely, based on various quantitative methods. The paper discusses some quantitative methods of multi-criteria decision-making (MCDM), namely Analytical Hierarchy Process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and Weighted Linear Combination (WLC); and their use for innovation projects. Autonomous orders of objects (projects) are performed on the same basic data set by the above-mentioned methods, and they are compared with each other. The Spearman's rank correlation coefficient was used for mutual comparison. The test results showed that the investigated methods do not provide results with a close dependence, which means that the order of objects (projects) created depends on the method used.

Keywords: multi-criteria analysis, AHP, TOPSIS, WLC, correlation.

Uporządkowanie projektów innowacyjnych przez wielokryterialne metody podejmowania decyzji – porównanie

Streszczenie

W przypadku procesu integracji barierą są różnice ekonomiczne i społeczne pomiędzy jednostkami gospodarczymi. Wiele organów administracyjnych podejmuje rozsądne i aktywne wysiłki, aby ograniczyć istniejące nierówności. W praktyce często trzeba uporządkować różne kwestie i argumenty i na tej podstawie podjąć decyzję. Podejmowanie decyzji może być intuicyjne lub odwrotnie, oparte na różnych metodach ilościowych. W artykule omówiono metody ilościowe podejmowania decyzji wielokryterialnych (MCDM), a mianowicie: *Analitical Hierarchy Process* (AHP), *Technique for Preference by Clarity to Ideal Solution* (TOPSIS) oraz *Weighted Linear Combination*

(WLC) i ich wykorzystanie w projektach innowacyjnych. Autonomiczne oceny obiektów (projektów) wykonywane są na tym samym podstawowym zbiorze danych wspomnianymi metodami i są ze sobą porównywane. Do wzajemnych porównań wykorzystano współczynnik korelacji Spearmana. Wyniki testów wykazały, że badane metody nie dają wyników o ścisłej zależności, co oznacza, że kolejność tworzonych obiektów (projektów) zależy od zastosowanej metody.

Słowa kluczowe: analiza wielokryterialna, AHP, TOPSIS, WLC, korelacja.

JEL: C00, O43.