Business, Management and Education
ISSN 2029-7491 / eISSN 2029-6169
2019 Volume 17: 72–93
https://doi.org/10.3846/bme.2019.11014

COMPARATIVE ANALYSIS OF MULTICRITERIA DECISION-MAKING METHODS EVALUATING THE EFFICIENCY OF TECHNOLOGY TRANSFER

Lidija KRAUJALIENĖ *

Department of Financial Engineering, Faculty of Business Management, Vilnius Gediminas Technical University, Vilnius, Lithuania

Received 4 June 2019; accepted 31 July 2019

Abstract. *Purpose* – to find appropriate tools to measure the efficiency of the technology transfer process (TTP) in higher education institutions (HEIs). Scientific problem is a lack of methods measuring the efficiency of TTP. The objective – comparative analysis of efficiency evaluation methods.
Research methodology – the research methodology is based on a comparative analysis of the research papers on the advantages and disadvantages of methods suitable to evaluate the efficiency of TTP.
Findings – among some tools, FARE is highlighted for identifying the variables of TTP and assigning their weights, when TOPSIS – to rank the variables and identify the most important. MULTOMOORA and COPRAS methods with ranking abilities are suitable to select the number of HEIs. DEA method is intended for the economic evaluation of TTP efficiency in HEIs. The social sciences are strengthened by suitable founded tools to measure the efficiency of TTP in HEIs.
Research limitations – this paper is providing all advantages and disadvantages (limitations) of decision-making multicriteria methods.
Practical implications – the original structure of methods enabling stakeholders (HEIs, TTOs and public authorities) for efficient allocation of an organisation's financial resources, foresee the future goals for improving the efficiency of TTP.
Originality/Value – the original framework of methods incorporated into the one model, enabling related stakeholders (HEIs, TTOs and public authorities) allocate financial resources efficiently.

Keywords: efficiency, evaluation, technology transfer, methods.

JEL Classification: C44, O32, O34.

Introduction

During the tracking of HEIs research and innovation activities, management issues, efficiency evaluation tools, the most important factors, which can influence the results of technology transfer (TT), the concept of efficiency evaluation can be arranged in the context of HEIs.

Successful TT is a sensitive issue in the context of HEIs. Usually, researchers like more concentrating on their exciting topics of the research forgetting about the research priorities

*Corresponding author. E-mail: *lidija.kraujaliene@vgtu.lt*

of HEIs, and the government. Researchers searching for recognition are are interested in sharing their inventions, findings with society through research papers. Hence, they have little time, which is oriented for science-business collaboration activities in a bilateral project or contract works. To overcome this gap, TT activities are coming to push research results to be search for perspective ideas, protect them (if needed), contact with industry seeking of commercialization finalisation and economic benefit for HEIs. University-business activities, promoted by TTOs, brings economic utility, thus necessary for HEIs wellbeing. Many countries are investing in research and development (R&D) activities, but it is challenging to evaluate TTP without appropriate tools. The information about suitable tools valuing the TTP in HEIs is quite limited. Therefore, it is relevant to search for and analyse existing multicriteria decision-making methods appropriate for the evaluation of the efficiency of TTP. Thus, the objective of the research is a comparative analysis of efficiency evaluation methods. After efficiency evaluation results and the current situation's map, relevant changings could be implemented to improve TT performance in HEIs.

Among different HEI's performance variables, calculation methods as well as delivering the results outside to society (e.g. presenting results in the annual HEIs' reports), such problems exist as converging performance results to the one platform and also finding the suitable method for facilitation and evaluation of TTP performance in HEIs. Moreover, there is one more issue of determining the variables and improving them by raising the level of HEIs' economic results of TTP.

The methodology of this paper is intended to find a suitable approach to measure the efficiency of TTP performance in HEIs.

Decision-making methods serve to analyse the performance of universities. A number of research papers have been concluded that government investments are relating to the TT results implemented in HEIs. R&D and innovation activities in HEIs are significant. Different countries have identified strategic priority areas and governments are investing in these areas to develop and strengthen activities in specific fields to reach economic benefit.

The concept of evaluation of the TT results is formed based on the analysis of literature. Taking into account the aspect of Lithuanian culture, searching for performance variables to evaluate the TTP, data-gathering aspects, appropriate matchmaking methods is leading to the creation of the framework to evaluate HEIs' TTP economic results. European TT models are more close to Lithuanian culture than American. Next, some examples are provided.

The cases of Germany and Belgium are presented in Kurgonaitė's (2015) work on the analysis of good foreign experience in TT and commercialisation activities. The most developed countries have applied such TT model, when TTO is established outside universities, including the best specialists in TT, intellectual property (IP), commercialisation activities, what have the positive effect on economic results of HEIs. TTO serves for a few most prominent universities and hospitals in the countries. To ensure the connection with scientists, TTO specialists have planned periodically meetings with the researchers, at least one or two times per month. Strong TTO team is required, motivated researchers, pleasant entrepreneurial atmosphere, perspective sector, high level of the market abilities and well-developed funding possibilities (Kurgonaitė, 2015). In Lithuania, the government allows HEIs to create their roles relating to TT and commercialization activities. Since 2009 December, when the

order of the Minister of education and science takes effect, HEIs has been promoted to implement TT and commercialization activities (Order of the Ministry of Education and Science of the Republic of Lithuania, 2009).

A similar situation is in Massachusetts Institute of Technology (MIT) (in the Boston, Cambridge), working mostly in the biotechnology sector, and being successful in TT and commercialisation. MIT has a high concentration of the most prominent and leading research institutions – hospitals and universities. However here TTO is situated outside HEIs/ research organisations, and the culture developed here is positive in cooperation channel between TTO specialists and researchers. Around 40% of the newly started spin-off companies are formed by MIT's alumni. MIT's culture leads others to think in the way of "I can do it too", that ensures many opportunities (e.g. competitions of a business plan) to seek strategies and get advice. Dozens of MIT's students achieve venture capital funding. Thus, MIT TT model depends on surrounding nature and having an entrepreneurial community surrounding HEIs. TT is successful with a legal and relatively non-bureaucratic procedure, sufficient funds for IP protection and filing patents of HEIs. The formation of spin-offs (based on HEIs IP) and development of clusters requires talented staff: world-class scientists and researchers; TT professionals; entrepreneurial founders of start-ups or spin-offs and the work teams involving managers and scientists; knowledgeable investors not only for funding, but also for advising and guiding the company, etc. (Nelsen, 2005).

Every process is measuring by relevant indicators. Respondents could be included in the research helping to identify performance variables of the particular process, assigning the weights (if relevant).

1. Comparative analysis of multicriteria decision-making methods

During valuing the TTP, first of all, appropriate methods should be selected to find the framework to measure the efficiency of TTP. Therefore, there is the need to value multicriteria decision-making methods with its advantages and disadvantages in applying them for evaluation of the efficiency of TTP in HEIs. For that purpose, the comparative analysis of the most popular decision-making methods were performed (see Table 1). It is worth noting that there are some limitations in the data collecting (as the lack of data), in designing the database for implementation of research, as well as in applying certain tools due to restrictions of particular methods.

A brief discussion and comparative analysis of the presented methods is provided below.

Every multicriteria method has its advantages and disadvantages. To avoid disadvantages, and to avail advantages of methods, the simultaneous use of several methods would deliver the benefit. To solve the issue of evaluating the TTP, the concept of the framework and involved methods able to evaluate the efficiency of TTP is presented below.

There are three steps identified to start measuring the efficiency of TTP.

The **first step** is identifying the variables suitable to measure the efficiency of TTP in HEIs. The Factor Relationship (FARE) method is suitable to realize this goal and set weights for variables. It serves in the case of some various variables when the weights of their importance

Table 1. Advantages and disadvantages of multicriteria decision-making methods (compiled by author)

Method	Multicriteria evaluation	Used in performance-type problems	Concordance coef. of Kendall is required	Maximizing / minim. criteria values	Compare and evaluate the criteria	Not requiring to minimize criteria	More robust involving all stakeholders and interrelations between alternatives and objectives	Non-subjective	Subjective	Absolute evaluation	Normalization needed	Does not need external normalization	Pair-wise comparisons	A mixture of percentiles, ratios and raw data is permissible	To measure weights	Needs initial weights	Minor amount of initial data is required	Direction and strength, asked from experts	Assessing the best and the worst alternatives	Provides the most stable results in the case of input data oscillating	Easy to use	Programmable	Used in case of all maximizing criteria	Inconsistent	All the values should be positive	Expected utility theory	Huge amount of data required	Retrieves similar cases from existing database, proposes similar solution
COPRAS	X	X	–	X	X	X	X	X	–	X	X	–	–	X	–	–	–	–	X	X	X	–	–	–	–	–	–	–
MULTIMOORA	X	X	–	X	X	–	X	X	–	X	X	X	–	X	–	–	–	–	X	X	X	–	–	–	X	–	–	–
DEA	X	X	–	X	X	–	X	X	–	X	X	–	–	X	–	–	–	–	X	X	X	X	–	–	X	–	–	–
FARE	X	X	X	–	X	–	X	X	–	X	X	–	–	X	X	–	X	X	X	X	X	–	–	–	–	–	–	–
TOPSIS	X	X	–	–	X	–	X	X	–	X	X	–	–	X		–	–	–	X	X	X	X	–	–	–	–	–	–
SAW	X	X	–	–	X	–	–	X	–	X	X	–	–	X		–	–	–	X	–	X	X	X	–	X	–	–	–
PROMETHEE	X	X	–	–	X	X	–	X	–	X	X	–	–	X	–	–	–	–	X	–	X	X	–	–	–	–	–	–
VIKOR	X	–	–	–	X	–	–	X	–	X	X	–	–	X	–	X	–	–	X	–	–	X	–	–	–	–	–	–
MAUT	X	–	X	–	X	–	–	X	X	–	X	–	–	–	–	–	–	–	X	–	–	–	–	–	–	X	X	–
AHP	X	X	–	–	X	–	–	X		X	X	–	X	X	–	–	–	–	X	–	–	–	–	X	–	–	–	–
CBR	X	X	–	–	X	–	–	X		X	X	–	–	–	–	–	–	–	X	–	–	–	–	X	–	–	–	X
SMART	X	–	X	–	X	–	–	–	X	–	X	–	–	–	–	–	–	–	X	–	–	–	–	–	–	X	X	–

on the TTP are unknown. The FARE method requires specialists (respondents), in this case from the sphere of TT, commercialisation and innovation management. Specialists help to estimate the importance of suggested criteria to select the most important one, as well as to measure the distances of the most crucial variable following all other criteria. This framework of the research is able to identify variables by the impact influencing the TTP (Ginevičius, 2006, 2007), while Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method helps to rank variables by importance of TTP For the **second step**, HEIs should be selected to include them to the research sample. Some considerations exist in choosing the HEIs with TT and commercialisation performance results. Therefore, the ranking tools serve to select the research sample. For that goal, such ranking multicriteria tools as Multi-Objective Optimization by Ratio Analysis (MULTIMOORA) and Complex Proportional Assessment (COPRAS) are identified to rank the HEIs (A. Hafezalkotob & A. Hafezalkotob, 2015; Chatterjee, Mondal, Boral, Banerjee, & Chakraborty, 2017; Chatterjee, Athawale, & Chakraborty, 2011). When the variables and research sample are known, the final **third step** is intended to find the tool for the efficiency evaluation of the TTP in HEIs. Thus, the Data Envelopment Analysis (DEA) tool is identified to calculate the economic efficiency of TTP in universities (Palecková, 2016; Cook, Tone, & Zhu, 2014). All mentioned methods were selected and involved in the framework of efficiency evaluation of TTP.

Next, decision-making methods in Table 1 are discussed to understand their abilities and contribution to the efficiency evaluation process. Selected tools for Evaluation of TTP are comparing with other decision-making methods.

The FARE method serves to evaluate the TTP performance of HEIs in case of multicriteria decision-making system. Ginevičius (2006) has been developed the tool of the FARE to help of estimation of multicriteria weights (only one method with this possibility, see Table 1). It helps to assess the importance of variables analysed. The latter tool helps to provide the consistency of formed decision matrix. The central aspect of the FARE method is a superiority comparison having performed (one from all variables in the research), which is addressing for creation of decision-making system. While decision-making matrix has been already created, the most important variable has been selected among all other variables. The variable, which has the highest superiority total values are highlighted as the most critical variable since the superior level of the essential variable is equal to one or over than one in comparison with other variables (Chatterjee et al., 2017; Kazan, Özçelik, & Hobikoğlu, 2015).

The FARE tool is selected in the first research step based on the situation with a minor volume of initial data when the estimation of relationships is required (Ginevičius, 2006, 2007). In comparison with other multicriteria decision-making tools, the Simple Multi-Attribute Rating Technique (SMART) method is not suitable for the reason for its ability to convert weights to real factual numbers. Moreover, the overall framework of the method's implementation is quite complicated (Velasquez & Hester, 2013). In turn, the Analytic Hierarchy Process (AHP) is not suitable for the identification of variables because the principle is based on the pair-wise comparisons (Velasquez & Hester, 2013). The Case-Based Reasoning (CBR) tool is not suitable for identification of the variables because for applying this method we should have an existing database of various cases when the tool is proposing the solution of similar cases (Velasquez & Hester, 2013). Another tool of the Multi-Attribute Utility

Theory (MAUT) is also not applicable for implementation of efficiency evaluation of TTP because this is the method of expected utility theory measuring the best possible benefit, instead of a selection of the variables by their importance level (Velasquez & Hester, 2013). The Preference Ranking Organisation Method for Enrichment Evaluation (PROMETHEE) is the method, which is not providing a definite possibility to assign weights of variables (Velasquez & Hester, 2013). The VlseKriterijumslca Optimizacija I Kompromisno Resenje (VIKOR) method needs initial weights in advance; however, when you have only the names of variables, it is not possible to apply this method (Liu & Wang, 2011).

In turn, the TOPSIS method serves in determining the best and the worst alternative values for the variables of TTP. The TOPSIS is the technique suitable to select the best alternative from a system of other alternatives in the research sample. The most important advantage of the TOPSIS method is inability, when the best alternative, which was selected, has not only the smallest distance from the ideal solution but also the longest distance situating from the ideal worst solution. The TOPSIS final calculation results supply interested person with information helping to make some decisions, on the one hand, close to the best possible, when from another – far from the worst. These possibilities ensuring decision-makers (e.g. the head of HEI) to make decisions on the best alternative, and finally selecting one of the right decision for the organisation (Ginting, Fadlina, Siahaan, & Rahim, 2017; Džunić, Stanković, & Janković-Milić, 2018; Ding & Zeng, 2015).

The TOPSIS method was included in the TT efficiency evaluation model for simplicity of application framework, because it is programmable, and providing the most stable performance results in the case when input data is oscillating. The proposed efficiency evaluation model of TTP is input-oriented; therefore the TOPSIS method is ideally appropriate for evaluating every alternative, and its deviation magnitude is able to assess alternatives from the best and the worst concerning the average attained (Choudhury, 2015; Ding & Zeng, 2015).

The MULTIMOORA is proposed as a non-subjective and more robust tool in comparison with other methods using subjective estimation framework. This method is enabling to maximize and minimize the variables' values, similar to the COPRAS method. The MULTIMOORA method is based on quantitative numbers; therefore, it fits for the research. Besides, the latter tool has one limitation – the data incorporated to the research should be positive (Altuntas, Dereli, & Yilmaz, 2015; Karabasevic, Stanujkic, Urosevic, & Maksimovic, 2015).

The COPRAS method allows comparing the data and ranking it. Since 1994, the researchers from Vilnius Gediminas Technical University (VGTU) as Zavadskas, Kaklauskas and Sarka have been introduced the complex proportional multicriteria evaluation tool, named as the COPRAS. This method is appropriate for quantitative multicriteria evaluation of maximising and minimising the number of different variables.

The tool to measure efficiency is named the DEA. This method is involved in the efficiency evaluation model of TTP in HEIs. On the other hand, efficiency could also be evaluated by applying the DEA complex proportional assessment method (Nazarko & Šaparauskas, 2014; Stefano, Casarotto Filho, Vergara, & da Rocha, 2015). The DEA method is intended for the relative evaluation of individual efficiency or evaluation of the performance of a DMU (decision-making unit) within the target group of specific interest. The DEA is acting in a particular field of activity like health care, banking, agricultural sphere, the sector of education (incl.

higher education), other. DMU means the production of HEIs. The DEA is the tool which is applying to identify sources of inefficiency, management level (to compare manufacturing and service operations), rank universities, evaluate the efficiency of programmes/policies, quantitative evaluation of resources that help to reallocate them, evaluate the efficiency of emissions or energy efficiency, etc. (Liu, L. Y. Lu, W. M. Lu, & Lin, 2013; Wang, Wei, & Zhang, 2013; Zhang & Choi, 2013a; Zhang, Zhou, & Choi, 2013b).

The COPRAS quantitative multicriteria tool is applied with maximisation and minimisation of variables' values. It allows the user to compare and check calculated results easily. Going more deep into the comparative analysis of the COPRAS, it can be less stable in comparison with the SAW or the TOPSIS tools on the case of variation of data; thus the COPRAS is used separately from other methods. The COPRAS tool is suitable to compare and evaluate the variables, describing hierarchically structured complex dimensions, being on the same level of the hierarchy, and therefore, it is appropriate for efficiency evaluation of HEIs (A. Hafezalkotob & A. Hafezalkotob, 2015; Chatterjee et al., 2017).

The DEA is suggested for the efficiency evaluation of DMUs acting a convenient method, employing an input–output oriented model, which is minimising input and maximising output variables. It is available in the case of a mixture of ratios, percentiles, and raw data. The efficiency with the DEA method can be easily analysed and quantified, which is essential at the end of the study. The DEA method fits to evaluate the TTP in HEIs (Cook et al., 2014; Feruś, 2008).

There are some other general efficiency evaluation tools of economic performance; however, the practice of their use in the case of evaluation of TTO in HEIs have not been used before. In general, the goal of economic analyses is oriented for optimization of prevention, control, or monitoring of investments, and also to minimize the total expenditures. The choices of detection, control, and prevention are interdependent. The managers firstly should evaluate the efficiency of alternatives' costs on each step, before developing of new strategies or policies to improve HEIs' activities (Epanchin-Niell, 2017).

There are some frameworks, which are able to evaluate the efficiency of one or another activity. For instance, the potential approaches are suitable for cost-effective management or identifying an efficient allocation of resources (Shen, Han, Price, Lu, & Liu, 2017). One of the useful approaches is a cost-benefit analysis, which is appropriate to measure the efficiency of the cost of the project in order to determine the relation with investments. The model of cost-benefit analysis determines the case of whether benefits are higher than costs. Another approach of return on investment analysis is prioritizing the allocation of financial resources across some independent, discrete projects (e.g. cost efficiency ranking of the projects). The methodology of the last approach is able to identify the projects in decreasing order when the formula's sense lying on the ratio of benefits divided by costs. The third approach is named as "optimization", which is measuring the efficiency level of investments' (by maximising the utility of net) and creating management approaches to reach the best objective. Moving forward, the methodology to implement the optimisation model is dynamic optimization and optimal control, etc. within a bioeconomic system of modelling. Another efficiency evaluation framework is the optimal design of activity, which is measuring the optimal parameters to change behaviour or private decision-making to achieve management

goals. Some methods are proposed to apply the latter approach: dynamic optimization, or optimal control, etc., which composed for private decision-making (Epanchin-Niell, 2017; Beikler & Flemmig, 2015).

There are many analytical models for evaluating the economic status of health-care interventions, for instance. The Consolidated Health Economic Evaluation Reporting Standards (CHEERS) Statement means the evaluation of cost-consequence analyses and economic utility of interventions, and leaves for the user the space for interpretation of information. Cost-minimisation analyses (CMA) is suitable for the comparison of the costs of interventions with equivalent outcomes (focus on the costs and excluding outcomes). The cost-effectiveness analyses (CEA) model relates the measures of outcome with costs, which advantage is in informing of the additional outcome improvement between some interventions. The CEA measure is usually introduced in terms of incremental cost-effectiveness ratios ICERs, which are relating the difference in efficiency to the difference in the costs between various alternative interventions from 0 till 1 (Beikler & Flemmig, 2015).

The economic evaluation methods presented in this comparative research do not solve the issue of TTP evaluation tool, but this paper has proposed the framework of suitable methods appropriate to measure the efficiency of TTP in HEIs by incorporating them in the one evaluation model. The model of suggested efficiency evaluation framework consists of such selected methods as the FARE, TOPSIS, MULTIMOORA/COPRAS, and DEA. The reasons for a selection of such tools are more deeply analysed in Section 3, where the advantages and disadvantages of tools are provided.

2. Formulas to implement the efficiency evaluation of technology transfer process in higher education institutions

The formulas of applying the FARE tool is presented in a number of research works (Ginevičius, 2006, 2007, 2008, 2011), as well as the formulas of the TOPSIS (Zavadskas et al., 2016; Choudhury, 2015; Ding & Zeng, 2015; Song & Zheng, 2015; Behzadian, Otaghsara, Yazdani, & Ignatius, 2012). The MULTIMOORA method's formulas are described in many other research papers (A. Hafezalkotob & A. Hafezalkotob, 2015; A. Hafezalkotob, A. Hafezalkotob, & Sayadi, 2016; Akkaya, Turanoğlu, & Öztaş, 2015; Altuntas et al., 2015; Karabasevic et al., 2015; Lazauskas, Zavadskas, & Saparauskas, 2015a; Lazauskas, Kutut, & Zavadskas, 2015b; Obayiuwana & Falowo, 2015; Brauers & Zavadskas, 2010; Stanujkic, 2015a; Stanujkic, Zavadskas, Brauers, & Karabasevic, 2015b; Stanujkic, 2016; Liu, Fan, Li, & Chen, 2014; Liu, You, Lu, & Chen, 2015; Kildienė, Zavadskas, & Tamošaitienė, 2014), as the formulas of the COPRAS (Chatterjee et al., 2017, 2011; Mousavi-Nasab & Sotoudeh-Anvari, 2017; Rezazadeh, Sancholi, Rad, Feyzabadi, & Kadkhodaei, 2017; Rivera, Fajardo, A. J. Ávila, C. F. Ávila, & Martinez-Gómez, 2017; Zolfani et al. 2018; Liou et al., 2016; Mulliner, Malys, & Maliene, 2016; Xue, You, Zhao, & Liu, 2016; Bausys, Zavadskas, & Kaklauskas, 2015; Nguyen, Dawal, Nukman, Aoyama, & Case, 2015; Ghorabaee, Amiri, Sadaghiani, & Goodarzi, 2014; Hashemkhani Zolfani & Bahrami, 2014; Pitchipoo, Vincent, Rajini, & Rajakarunakaran, 2014; Zavadskas, Turskis, & Kildienė, 2014; Aghdaie, Zolfani, & Zavadskas, 2013; Tavana, Momeni, Rezaeiniya, Mirhedayatian, & Rezaeiniya, 2013; Ginevičius, 2008; Kracka et al., 2010;

Tupenaite et al., 2010; Kaklauskas et al., 2006, 2010; Turskis, Zavadskas, & Peldschus, 2009). The DEA method's approach and formulas are discussed in other research projects (Paleckova, 2016; Cook et al., 2014; Feruś, 2008; Simar & Wilson, 2007).

The formulas should be analysed before their's implementation taking into account the advantages and disadvantages of precise method. Proposed methods as the FARE, TOPSIS, MULTIMOORA, COPRAS, and DEA are quite easy in use and understandable in the application. Section 3 is presenting the comparative analysis on the advantages and disadvantages of efficiency evaluation methods.

3. Comparative analysis of advantages and disadvantages of efficiency evaluation methods

This section is analysing the advantages and disadvantages of a number of the most popular decision-making methods in the economic arena.

This research paper is intended to search for suitable tools to evaluate the efficiency of TTP in such organizations as HEIs.

After a brief analysis of decision-making methods we see, that the most suitable tools to measure the efficiency of TTP are the FARE, TOPSIS, MULTIMOORA/COPRAS, and DEA. However, there are many other multicriteria tools discussed in this paper.

The COPRAS (Complex Proportional Assessment) method's advantages and disadvantages are presented in Table 2.

The COPRAS tool is suitable to measure the variables of the multicriteria system while maximising and minimising the values, compare the variables, what is needed to identify the research sample of HEIs. Also, it is convenient, that is not requiring minimisation of the

Table 2. Advantages and disadvantages of the COPRAS decision-making method (compiled by author, based on A. Podviezko & V. Podvezko, 2014; Podvezko, 2011)

The COPRAS method		
No	Advantages	Disadvantages
1	The method is used for evaluation of the multicriteria system of variables for maximising and minimising the values	COPRAS may be less stable in comparison with SAW or TOPSIS methods in data variation case
2	The method allows to compare and also check the final results of measuring easily	The results may be sensitive to a slight variation of data, and the ranks devoted may differ from ones obtained with other methods
3	The typical properties of the tool allow being used to implement the comparison and evaluation of variables describing hierarchically structured complex magnitudes, positioning on the same hierarchical level	
4	This tool is not requiring such transformation as minimising the variables; therefore the transformation of the data is not distorted; this tool is appropriate to evaluate a single alternative	

variables, and the transformation of the data is not strained. Attention should be paid to the data variation because the COPRAS could be less stable than the SAW or TOPSIS, and the calculation results may be sensitive relating to data variation. Nevertheless, based on several advantages, the COPRAS was included in the framework of efficiency evaluation of TTP.

Table 3. Advantages and disadvantages of the MULTIMOORA decision-making method (compiled by author, based on Brauers & Zavadskas, 2010)

The MULTIMOORA method		
No	Advantages	Disadvantages
1	Comparing the MULTIMOORA method with other tools, it is more robust and involving all related stakeholders (including sovereignty of the consumer), interested in a particular issue like an advantage.	The MULTIMOORA has one disadvantage in the data of objectives used in the database, when the data cannot be equal to the zero or dealing with the negative numbers.
2	The MULTIMOORA method with all non-correlated goals is more robust in comparison with a limited number of goals.	
3	The MULTIMOORA tool is more robust, when all objectives' and alternatives' interrelations are taken into account, and simultaneously in comparison with interrelations when only investigated two by two.	
4	The MULTIMOORA method is non-subjective from one side, and more robust comparing with tools applying subjective estimations to implement the choice for importance and normalisation of the objectives.	
5	The choice to set objectives. A system of robust objectives would be identified after the session of brainstorming technique with all the stakeholders or representative experts. Normalisation. The MILTIMOORA is the tool that does not need external normalisation and more robust in comparison with such based on the subjective external normalisation. This multiple objectives' method is lying on dimensionless non-subjective measures without normalisation, in that way become more robust compared with methods, which are using subjective non-additive values or subjective weights. Giving the importance of the objective. Together with the scores and weights, the importance of some objectives is mixed with normalisation.	
6	The MULTIMOORA method is based on quantitative numbers, and it is more robust than other tools based on ordinal measures.	
7	The MULTIMOORA method with the available data is the base for more robust studies than based on earlier available data.	
8	The application of two methods of multi-criteria objective's optimisation is more robust in comparison with applying a single one; when the application of three tools is more robust than applying two tools, etc.	

We see in Table 3 that the MULTIMOORA method has many advantages and only one disadvantage. This method is more robust and involving all related stakeholders, interested in certain economic problem-solving. All interrelations of objectives and alternatives have been taken into account, and the MULTIMOORA does not need external normalisation. For the reason of several advantages and abilities, in case of a multicriteria system of TTP, this method is a suitable tool, involved in the efficiency evaluation framework of TTP in HEIs.

The DEA tool input-output oriented method is presented in the research papers as a convenient programmable method to evaluate the efficiency of the decision-making unit working in different spheres (see Table 4). The efficiency could be easily analysed and quantified. A mixture of raw data, ratios, and percentiles is available for calculations, what has an

Table 4. Advantages and disadvantages of the DEA decision-making method (compiled by author, based on Cook et al., 2014; Velasquez & Hester, 2013; Banker, Charnes, Cooper, Swarts, & Thomas, 1989)

The DEA method		
No	Advantages	Disadvantages
1	Efficiency evaluation method, input-output oriented method, which is maximising output and minimising input variables; the tool is based on proportional reduction.	The number of alternatives analysed is that the sample should be at least twice lower than the number of inputs measures and outputs combined. When Banker (1989) has been stated, that the number of variables should be at least three times higher than the number of outputs and inputs.
2	This method is able to handle multiple outputs and inputs.	Potential issues are existing during the selection of the variables for the DEA tool when the raw data (e.g. revenues, the number of employees, assets, profits, etc.) and the ratios (e.g. returns on investment) would not be incorporated in the one model.
3	The tool is suitable to measure the efficiency that can be analysed and quantified.	The method does not deal with an inaccurate number of data and suppose that all output and input measures are known. However, in real life, this assumption would not be true.
4	The method is able to uncover relationships, which may be in hidden under other methods.	The method does not deal with an inaccurate number of data and suppose that all output and input measures are known. However, in real life, this assumption would not be valid.
5	A mixture of ratios, raw data and percentiles are permissible in one calculation of efficiency with the DEA method.	The measurement results could be sensitive depending on the identified outputs and inputs.
6	The DEA method is widely used in economic, road safety, medical, utilities, retail, business and agriculture problem-solving. These categories have precise data using for the input, which deficiencies avoid one of the significant tool's.	
7	The tool is programmable and quite effortless in use.	

advantage in case of missing data from one source, or similar. This tool fits to measure the efficiency however has some disadvantages, like the number of units in the samples should be at least twice higher than the number of alternatives, and others. Therefore, due to the DEA advantages, this tool is selected and involved in the frameworks to measure the efficiency of TTP in HEIs.

The TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) tool (Table 5) is based on that principle: the optimal dote should have the farthest point in the distance from the negative ideal solution point and the shortest line from the positive ideal solution (Liu & Wang, 2011).

The TOPSIS tool serves the function of ranking identifying the variables (with the FARE method), which will be involved in the evaluation of the efficiency of TTP. The TOPSIS is easy to use, not requiring minimisation of variables, and applicable in many different areas. Therefore, the TOPSIS method was selected for the framework of efficiency evaluation of TTP in HEIs.

Table 5. Advantages and disadvantages of the TOPSIS decision-making method (compiled by author, based on A. Podviezko & V. Podvezko, 2014; Velasquez & Hester, 2013)

The TOPSIS method		
No	Advantages	Disadvantages
1	This absolute evaluation tool, which is not requiring transformation to minimize the variables; the data transformation is not perverted.	The application of Euclidean Distance does not look to the correlation of the attributes.
2	The TOPSIS method is allowing to interpret the absolute evaluation of certain alternative, its deviation magnitude assessing the results starting from the best and the worst average alternatives.	In this tool is quite difficult to weight and also keep the consistency of judgment, particularly with additional attributes.
3	This tool is providing the possibility of the most stable performance results in case the input data is varying.	
4	The research of developing hypothetical worst and best objects is suitable for certain tasks are worth to be started in many areas, where quantitative evaluation is needed.	
5	The TOPSIS is based on the simple process; it is programmable and easy to apply.	
6	The TOPSIS method is easy in terms of maintaining the same number of steps in regard to the size of the problem.	
7	The TOPSIS tool is widely in use for areas like logistics, manufacturing systems and engineering, environmental management, marketing management, design, business, water and human resources management.	

Table 6. Advantages and disadvantages of the SAW decision-making method (compiled by author, based on Podvezko, 2011; A. Podviezko & V. Podvezko, 2014)

The SAW method		
No	Advantages	Disadvantages
1	This tool is able to compensate among variables	The SAW method may be applied if all the variables are maximising (and transformed into maximising variables) before analysis.
2	Intuitive method for decision-makers; the way of measuring is quite simple and does not require several computer programs or tools.	All the values of the variables should be positive. The calculation is depending on the type of transformation converting to positive dimensions.
3	This tool integrates the values of variables and weights into a single one magnitude.	The largest dimension of the variable of the SAW tool maybe about unity, while the smallest dimension may reach the 0.
4	The calculation algorithm of this method is not complicated and can be implemented without the computer tools or by using a simple computer program.	The SAW method's estimates yielded do not always reflect the real status. The result may not be in terms with logic, with the measures of one particular variable widely differing from once of other variables.
5	Normalised values of the evaluation help visually calculate the differences between the alternatives.	The SAW tool is based on normalisation, with minimising the variables, converting to the maximising.
6	This tool is suitable to evaluate a singlealternative.	Result gathered may not be logical.

The SAW method (Table 6) would fit to value the efficiency of TTP in HEIs, but we see many disadvantages of carrying out this tool: the method may be applied in case when all variables are maximising and positive, the result may not be in terms with logic. Therefore, this tool, despite that fact that it also has advantages, was not selected to the framework for evaluation model of efficiency of TTP in HEIs.

Table 7. Advantages and disadvantages of the PROMETHEE decision-making method (compiled by author, based on A. Podviezko & V. Podvezko, 2014; Velasquez & Hester, 2013)

The PROMETHEE method		
No	Advantages	Disadvantages
1	This tool is not needed the transformation for minimising the variables, and the data transformation in case this method is not distorted.	This tool does not provide a clear framework for assigning the weights.
2	The PROMETHEE is easy in application.	This tool is requiring the assignment of measures, although it does not provide an understandable framework to assign the values.
3	It does not require the criteria to be proportionate.	
4	Widely used in such area as financial management, environmental, business management, management in general, water management and hydrology, chemistry, manufacturing, assembly, agriculture, transportation, logistics, energy management.	
5	This tool needs normalisation.	

The PROMETHEE tool in Table 7 does not provide a logical and accessible framework to assign values and weights. Therefore this method was not involved in the framework of efficiency evaluation of TTP in HEIs.

Table 8. Advantages and disadvantages of the VIKOR decision-making method (compiled by author, based on J. K. Chen & I. Chen, 2008; Velasquez & Hester, 2013)

The VIKOR method		
No	Advantages	Disadvantages
1	The method is based on the principle of multi-criteria decision making (MCDM) system's compromise programming.	The ranking needs can be performed with different values of variables' weights.
2	This method is supporting multicriteria decision-maker in such cases, when he is unstable, or when there is no idea to express one's preference, e.g. at the beginning of creating the system.	The analysis of the impact is applied from the side of all weights of variables on a suggested compromise solution.
3	A compromise solution is applicable based on the maximum group utility, and also on an individual regret's minimum.	This tool needs initial weights.
4	The result of ranking is the list of alternatives after special compromise ranking and the solution with an advantage rate.	Suitable in such cases when the information is in numerical values.
5	The VIKOR method is determining the stability intervals in weights.	
6	The compromise solution in the VIKOR tool will be replaced if the measure of weight does not fit in the stability interval.	
7	Single variable analysis of weight's stability intervals is used for all variables functions, with initial measures of weights. The stability of an acquired compromise solution could be analysed with the VIKOR electronic program.	
8	This tool needs normalisation.	

This tool (Table 8) means the optimisation and compromise solution of multi-criteria system (Liu & Wang, 2011).

The VIKOR method requires initial weights because it is determining the stability intervals in weights. When we do not have weights in advance, this tool is not suitable. For that reason, this method is not involved in the suggested framework to evaluate the efficiency of TTP in HEIs.

The MAUT (Multi-Attribute Utility Theory) means an expected utility theory; it can conclude on the best action for a given issue and measure the best possible benefit (Velasquez & Hester, 2013).

The MAUT tool is not suitable in case of TT (Table 9), because it is requiring a huge number of inputs on every step when HEIs do not gather vast number of information relating TT. Therefore this tool is exceptionally intensive in data. Usually, indicators in Strategic plans value the activities of HEIs. There are not many indicators relating TT, so HEIs do not have huge information on that purpose. The MAUT method is not suitable for valuing the efficiency of TTP in HEIs.

Table 9. Advantages and disadvantages of the MAUT decision-making method (compiled by author, based on Velasquez & Hester, 2013)

The MAUT method		
No	Advantages	Disadvantages
1	The MAUT method is taking uncertainty into account.	The considerable volume of input is required at every step in order to record preferences of the decision-maker, and making this method extremely intensive in data.
2	It is comprehensive; besides, it can evaluate the preferences of every consequence in all calculation steps of the tool.	The level of input measures and the massive number of data may not be available for a particular decision-making problem.
3	The MAUT tool is widely applicable in economic, water management, financial, actuarial, agricultural, and energy management problem-solving. All mentioned types of issues have significant amounts and uncertainty of available data, which should be enough to make the MAUT method a proper technique for decision-making.	The precise preferences of the decision-makers should be done.
4	This tool needs normalisation in order to eliminate the influence of various physical values on decision-making.	Stronger assumptions are requiring on every level. Therefore, it would be relatively subjective and challenging to apply.

Table 10. Advantages and disadvantages of the AHP decision-making method (compiled by author, based on Velasquez & Hester, 2013)

The AHP method		
No	Advantages	Disadvantages
1	This tool is easy to apply.	Interdependence between variables and alternatives.
2	A scalable tool that easily adjusts in size to application in solving decision-making problems according to their hierarchical structure.	Due to the tool of pairwise comparisons, the AHP is able to be the subject to inconsistencies during ranking and judgment variables.
3	The AHP method is intensively comparing to the MAUT method. Although, the AHP requires a quite significant amount of the data to implement pairwise comparisons suitably.	The AHP method does not allow the user grading one instrument separately, however only in comparison with the all rest, without finding the strengths or weaknesses.
4	The AHP tool is widely used in performance-type problem-solving, corporate strategy and policy, public policy, resource management, political strategy and planning. Resource management issues solve the limitation of rank reversal based on the limited number of alternatives. The AHP tool is appropriate to handle more significant problems making them perfect to handle issues, which are comparing the results between alternatives.	The overall form of the AHP method is susceptible to reversal of the ranking function. Due to the specific of comparisons, the supplement of alternatives at the end of the measurement process could lead to the reverse of the final results of rankings.
5	Hierarchy structure can easily be adjusted to fit a lot of sized issues.	

The method of AHP (Analytic Hierarchy Process) was analysed. The primary characteristic of this tool is pairwise comparisons, which are appropriate to compare many alternatives in the cases of different variables, serving for estimating the weights of the variables. This method is relying on the judgments of selected specialists-experts to derive the priority scales.

The AHP (Table 10) is the tool of pairwise comparisons, requiring the big amount of the data, therefore this tool is not suggested for the efficiency evaluation framework of TTP in HEIs.

Table 11. Advantages and disadvantages of the CBR decision-making method (compiled by author, based on Velasquez & Hester, 2013)

The CBR method		
No	Advantages	Disadvantages
1	This method is requiring a little effort for gaining the process of additional data	The sensitivity to inconsistency in different data.
2	The CBR tool is not data intensive.	It requires many cases.
3	Minimum expenditure on maintenance of the data-system is needed, requiring little funding for maintenance.	The CBR is implemented in such industries in a substantial number of existing previous cases (medicine, engineering designs, comparisons of businesses, vehicle insurance).
4	This tool can improve its ability over time when more and more cases are included in the maintaining data-system.	
5	The CBR method can adapt to changes in the surrounding environment with its created and used database of a big number of cases.	

Moving forward, the CBR (Case-Based Reasoning) method is analysed in Table 12. The CBR method is the tool retrieving the cases very similar to an issue from an existing data-system of various variants. The CBR is proposing a solution for the decision-maker based on similar cases in the existing database (Velasquez & Hester, 2013).

The CBR method (Table 11) is not data-intensive, but it requires many cases and sensitive to inconsistency in different data. In the case of HEIs TT activities, there are different data in number, ratios, dimensions. Therefore this CBR method is not suggested for an efficiency evaluation framework.

The SMART (Simple Multi-Attribute Rating Technique) is one of the simplest forms of the MAUT method, conveniently converting weights to the actual numbers (Velasquez & Hester, 2013).

The SMART tool (Table 12), analysed in Table 12, due to it is a complicated framework, and only open, accessible data suitable for the tool, it is not suggested for the efficiency evaluation framework of TTP in HEIs.

After analysing several presented multicriteria decision-making methods, the framework to evaluate the efficiency of TTP in HEIs is proposed. Several methods are not suitable due to its disadvantages or application conditions, mentioned above after every method's analysis. The framework of efficiency evaluation of TTP in HEIs is proposed next: FARE method firstly integrated to identify the variables and their importance of TTP in

Table 12. Advantages and disadvantages of the SMART decision-making method (compiled by author, based on Velasquez & Hester, 2013)

The SMART method		
No	Advantages	Disadvantages
1	The MAUT method, all advantages is adapted.	The procedure for determining work is quite difficult and not very friendly, considering the complicated framework for the user.
2	This method is allowing assignment techniques (absolute, relative, etc.) for any type of weight.	The SMART method is easy to use when there is a fair amount of information, and it is openly accessible, available for the decision-maker.
3	It requires less effort for users in comparison with the MAUT.	
4	It also handles the informative data well under every variable.	
5	This tool is usually solving issues in such spheres as transportation and logistics, military, environmental, manufacturing, construction, assembly.	
6	It is an accessible and understandable tool.	

HEIs, when the TOPSIS method is proposed to rank the variables by their importance on the process. The MULTIMOORA or the COPRAS multicriteria decision-making methods are suggested to rank HEIs and to select the research sample. The DEA method is selected to calculate the efficiency of decision-making units (HEIs).

Conclusions

This research is suggesting the framework of evaluating the efficiency of decision-making units, in this case – HEIs, to value the performance of the technology transfer process. This is leading with searching for appropriate methods (tools) to measure the efficiency of technology transfer in HEIs. The higher education organisations are particular, and the activity of TT and commercialisation. HEIs in Lithuania is on the way of developing the policy for initiation, protection and commercialisation of HEIs intellectual property in comparison with other countries abroad.

After the implementation of the comparative analysis of economic decision-making tools, it is possible to propose the model to evaluate the efficiency of TTP in HEIs. This model is constructed from the complex of decision-making tools suitable to perform a particular function. Thus, FARE method is suggested to select the variables, estimate their weights and evaluate the importance on the TTP in HEIs. The TOPSIS method is allowing to rank the variables and select the most critical variable for the research. The MULTMOORA and the COPRAS tools are suitable for ranking function in estimating the number of research sample composing from HEIs, which have valuable results in implementing the intellectual property management and commercialisation activities. The DEA tool is entirely suitable for the

evaluation of the efficiency of TTP in HEIs. Due to different applicability and nuances, other presented methods in this research work as the SMART, CBR, AHP, MAUT, PROMETHEE, VIKOR, and SAW are suitable in measuring other processes, but not TTP in HEIs.

For further research would be useful to analyse the impact of new strategic initiatives on the TTP relating to economic benefit.

References

Aghdaie, M. H., Zolfani, S. H., & Zavadskas, E. K. (2013). Market segment evaluation and selection based on application of fuzzy AHP and COPRAS-G methods. *Journal of Business Economics and Management*, *14*(1), 213-233. https://doi.org/10.3846/16111699.2012.721392

Akkaya, G., Turanoğlu, B., & Öztaş, S. (2015). An integrated fuzzy AHP and fuzzy MOORA approach to the problem of industrial engineering sector choosing. *Expert Systems with Applications*, *42*(24), 9565-9573. https://doi.org/10.1016/j.eswa.2015.07.061

Altuntas, S., Dereli, T., & Yilmaz, M. K. (2015). Evaluation of excavator technologies: application of data fusion based MULTIMOORA methods. *Journal of Civil Engineering and Management*, *21*(8), 977-997. https://doi.org/10.3846/13923730.2015.1064468

Bausys, R., Zavadskas, E. K., & Kaklauskas, A. (2015). *Application of neutrosophic set to multicriteria decision making by COPRAS*. Infinite Study.

Beikler, T., & Flemmig, T. F. (2015). EAO consensus conference: economic evaluation of implant-supported prostheses. *Clinical Oral Implants Research*, *26*, 57-63. https://doi.org/10.1111/clr.12630

Banker, R. D., Charnes, A., Cooper, W. W., Swarts, J., & Thomas, D. (1989). An introduction to data envelopment analysis with some of its models and their uses. *Research in Governmental and Nonprofit Accounting*, *5*, 125-163.

Behzadian, M., Otaghsara, S. K., Yazdani, M., & Ignatius, J. (2012). A state-of the-art survey of TOPSIS applications. *Expert Systems with Applications*, *39*(17), 13051-13069. https://doi.org/10.1016/j.eswa.2012.05.056

Brauers, W. K. M., & Zavadskas, E. K. (2010). Project management by MULTIMOORA as an instrument for transition economies. *Technological and Economic Development of Economy*, *16*(1), 5-24. https://doi.org/10.3846/tede.2010.01

Chatterjee, P., Mondal, S., Boral, S., Banerjee, A., & Chakraborty, S. (2017). A novel hybrid method for non-traditional machining process selection using factor relationship and Multi-Attributive Border Approximation Method. *Facta Universitatis, Series: Mechanical Engineering*, *15*(3), 439-456. https://doi.org/10.22190/FUME170508024C

Chatterjee, P., Athawale, V. M., & Chakraborty, S. (2011). Materials selection using complex proportional assessment and evaluation of mixed data methods. *Materials & Design*, *32*(2), 851-860. https://doi.org/10.1016/j.matdes.2010.07.010

Chen, J. K., & Chen, I. (2008). VIKOR method for selecting universities for future development based on innovation. *Online Submission*.

Choudhury, K. (2015). Evaluating customer-perceived service quality in business management education in India: A study in topsis modeling. *Asia Pacific Journal of Marketing and Logistics*, *27*(2), 208-225. https://doi.org/10.1108/APJML-04-2014-0065

Cook, W. D., Tone, K., & Zhu, J. (2014). Data envelopment analysis: Prior to choosing a model. *Omega*, *44*, 1-4. https://doi.org/10.1016/j.omega.2013.09.004

Ding, L., & Zeng, Y. (2015). Evaluation of Chinese higher education by TOPSIS and IEW – The case of 68 universities belonging to the Ministry of Education in China. *China Economic Review*, *36*, 341-358. https://doi.org/10.1016/j.chieco.2015.05.007

Džunić, M., Stanković, J., & Janković-Milić, V. (2018). Multi-criteria approach in evaluating contribution of social entrepreneurship to the employment of socially-excluded groups. *Technological and Economic Development of Economy*, *24*(5), 1885-1908. https://doi.org/10.3846/20294913.2017.1347906

Epanchin-Niell, R. S. (2017). Economics of invasive species policy and management. *Biological Invasions*, *19*(11), 3333-3354. https://doi.org/10.1007/s10530-017-1406-4

Feruś, A. (2008). The dea method in managing the credit risk of companies. *Ekonomika/Economics*, *84*.

Ghorabaee, M. K., Amiri, M., Sadaghiani, J. S., & Goodarzi, G. H. (2014). Multiple criteria group decision-making for supplier selection based on COPRAS method with interval type-2 fuzzy sets. *The International Journal of Advanced Manufacturing Technology*, *75*(5-8), 1115-1130. https://doi.org/10.1007/s00170-014-6142-7

Ginevičius, R. (2011). A new determining method for the criteria weights in multicriteria evaluation. *International Journal of Information Technology & Decision Making*, *10*(06), 1067-1095. https://doi.org/10.1142/S0219622011004713

Ginevičius, R. (2006). Multicriteria evaluation of the criteria weights based on their interrelationship. *Business: Theory and Practice*, *7*, 3-13.

Ginevičius, R. (2007). A comparative analysis of the criteria weights determined by using multicriteria evaluation methods AHP and FARE. *4th International Scientific Conference "Enterpsire Management: Diagnosis, Strategy, Efficiency"* (pp. 16-18). Vilnius: Technika.

Ginevičius, R. (2008). Normalisation of quantities of various dimensions. *Journal of Business Economics and Management*, (1), 79-86. https://doi.org/10.3846/1611-1699.2008.9.79-86

Ginting, G., Fadlina, M., Siahaan, A. P. U., & Rahim, R. (2017). Technical approach of TOPSIS in decision making. *International Journal of Recent Trends in Engineering & Research*, *3*(8), 58-64. https://doi.org/10.23883/IJRTER.2017.3388.WPYUJ

Hafezalkotob, A., Hafezalkotob, A., & Sayadi, M. K. (2016). Extension of MULTIMOORA method with interval numbers: an application in materials selection. *Applied Mathematical Modelling*, *40*(2), 1372-1386. https://doi.org/10.1016/j.apm.2015.07.019

Hafezalkotob, A., & Hafezalkotob, A. (2015). Comprehensive MULTIMOORA method with target-based attributes and integrated significant coefficients for materials selection in biomedical applications. *Materials & Design*, *87*, 949-959. https://doi.org/10.1016/j.matdes.2015.08.087

Hashemkhani Zolfani, S., & Bahrami, M. (2014). Investment prioritizing in high tech industries based on SWARA-COPRAS approach. *Technological and Economic Development of Economy*, *20*(3), 534-553. https://doi.org/10.3846/20294913.2014.881435

Kaklauskas, A., Zavadskas, E. K., Naimavicienė, J., Krutinis, M., Plakys, V., & Venskus, D. (2010). Model for a complex analysis of intelligent built environment. *Automation in Construction*, *19*(3), 326-340. https://doi.org/10.1016/j.autcon.2009.12.006

Kaklauskas, A., Zavadskas, E. K., Raslanas, S., Ginevičius, R., Komka, A., & Malinauskas, P. (2006). Selection of low-e windows in retrofit of public buildings by applying multiple criteria method COPRAS: A Lithuanian case. *Energy and Buildings*, *38*(5), 454-462. https://doi.org/10.1016/j.enbuild.2005.08.005

Karabasevic, D., Stanujkic, D., Urosevic, S., & Maksimovic, M. (2015). Selection of candidates in the mining industry based on the application of the SWARA and the MULTIMOORA methods. *Acta Montanistica Slovaca*, *20*(2).

Kazan, H., Özçelik, S., & Hobikoğlu, E. H. (2015). Election of deputy candidates for nomination with AHP-PROMETHEE methods. *Procedia-Social and Behavioral Sciences*, *195*, 603-613. https://doi.org/10.1016/j.sbspro.2015.06.141

Kracka, M., Brauers, W. K. M., & Zavadskas, E. K. (2010). Ranking heating losses in a building by applying the MULTIMOORA. *Engineering Economics, 21*(4), 352-359.

Kildienė, S., Zavadskas, E. K., & Tamošaitienė, J. (2014). Complex assessment model for advanced technology deployment. *Journal of Civil Engineering and Management*, *20*(2), 280-290. https://doi.org/10.3846/13923730.2014.904813

Kurgonaitė, K. (2015). Technologijų perdavimo proceso kūrimas, kaip viena iš priemonių efektyvesniam mokslo ir verslo bendradarbiavimui skatinti. *JPP Kurk Lietuvai*.

Lazauskas, M., Kutut, V., & Zavadskas, E.-K. (2015b). Multicriteria assessment of unfinished construction projects, *Gradevinar, 67*(4), 319-328.

Lazauskas, M., Zavadskas, E.-K., & Saparauskas, J. (2015a). Ranking of priorities among the Baltic capital cities for the development of sustainable construction. *E and M Ekonomie a Management, 18*(2), 15-24. https://doi.org/10.15240/tul/001/2015-2-002

Liou, J.-J.; Tamošaitienė, J.; Zavadskas, E.-K.; Tzeng, G.-H. 2016. New hybrid COP-RAS-G MADM Model for improving and selecting suppliers in green supply chain management. *International Journal of Production Research, 54*(1), 114-134.

Liu, P., & Wang, M. (2011). An extended VIKOR method for multiple attribute group decision making based on generalized interval-valued trapezoidal fuzzy numbers. *Scientific Research and Essays*, *6*(4), 765-776.

Liu, H. C., Fan, X. J., Li, P., & Chen, Y. Z. (2014). Evaluating the risk of failure modes with extended MULTIMOORA method under fuzzy environment. *Engineering Applications of Artificial Intelligence*, *34*, 168-177. https://doi.org/10.1016/j.engappai.2014.04.011

Liu, H. C., You, J. X., Lu, C., & Chen, Y. Z. (2015). Evaluating health-care waste treatment technologies using a hybrid multi-criteria decision making model. *Renewable and Sustainable Energy Reviews*, *41*, 932-942. https://doi.org/10.1016/j.rser.2014.08.061

Liu, J. S., Lu, L. Y., Lu, W. M., & Lin, B. J. (2013). A survey of DEA applications. *Omega*, *41*(5), 893-902. https://doi.org/10.1016/j.omega.2012.11.004

Mousavi-Nasab, S. H., & Sotoudeh-Anvari, A. (2017). A comprehensive MCDM-based approach using TOPSIS, COPRAS and DEA as an auxiliary tool for material selection problems. *Materials & Design*, *121*, 237-253. https://doi.org/10.1016/j.matdes.2017.02.041

Mulliner, E., Malys, N., & Maliene, V. (2016). Comparative analysis of MCDM methods for the assessment of sustainable housing affordability. *Omega*, *59*, 146-156. https://doi.org/10.1016/j.omega.2015.05.013

Nazarko, J., & Šaparauskas, J. (2014). Application of DEA method in efficiency evaluation of public higher education institutions. *Technological and Economic Development of Economy*, *20*(1), 25-44. https://doi.org/10.3846/20294913.2014.837116

Nelsen, L. L. (2005). The role of research institutions in the formation of the biotech cluster in Massachusetts: The MIT experience. *Journal of Commercial Biotechnology*, *11*(4), 330-336. https://doi.org/10.1057/palgrave.jcb.3040134

Nguyen, H. T., Dawal, S. Z. M., Nukman, Y., Aoyama, H., & Case, K. (2015). An integrated approach of fuzzy linguistic preference based AHP and fuzzy COPRAS for machine tool evaluation. *PloS One*, *10*(9), e0133599. https://doi.org/10.1371/journal.pone.0133599

Obayiuwana, E., & Falowo, O. (2015, September). A multimoora approach to access network selection process in heterogeneous wireless networks. In *AFRICON 2015* (pp. 1-5). IEEE. https://doi.org/10.1109/AFRCON.2015.7331973

Order of the Ministry of Education and Science of the Republic of Lithuania. (2009). *Regarding recommendations for Lithuanian research and study institutions to approve the rights resulting from the intellectual activities*, Nr. ISAK-2462. Retrieved from https://e-seimas.lrs.lt/portal/legalActPrint/lt?jfwid=ky1aszbvn&documentId=TAIS.360411&category=TAD

Palecková, I. (2016, May 12-13). Cost efficiency of the Czech and Slovak banking sectors: an application of the data envelopment analysis. *9th International Scientific Conference of "Business and Management 2016"*. Vilnius, Lithuania. https://doi.org/10.3846/bm.2016.14

Pitchipoo, P., Vincent, D. S., Rajini, N., & Rajakarunakaran, S. (2014). COPRAS decision model to optimize blind spot in heavy vehicles: A comparative perspective. *Procedia Engineering*, *97*, 1049-1059. https://doi.org/10.1016/j.proeng.2014.12.383

Podvezko, V. (2011). Comparative analysis of MCDA methods SAW and COPRAS. *Inžinerinė Ekonomika*, 134-146. https://doi.org/10.5755/j01.ee.22.2.310

Podviezko, A., & Podvezko, V. (2014). Absolute and relative evaluation of socio-economic objects based on multiple criteria decision making methods. *Engineering Economics*, *25*(5), 522-529. https://doi.org/10.5755/j01.ee.25.5.6624

Rezazadeh, M. H., Sancholi, B., Rad, S. S., Feyzabadi, A. N., & Kadkhodaei, M. (2017). Ranking of Zahedan's five districts in order to fulfill the creative city. *Journal of History Culture and Art Research*, *6*(1), 703-719. https://doi.org/10.7596/taksad.v6i1.776

Rivera, E. D., Fajardo, C. A., Ávila, A. J., Ávila, C. F., & Martinez-Gómez, J. (2017). Material selection of induction cookware based on multi criteria decision making methods (MCDM). *Rev Técn Energıa*.

Simar, L., & Wilson, P. W. (2007). Estimation and inference in two-stage, semi-parametric models of production processes. *Journal of Econometrics*, *136*(1), 31-64. https://doi.org/10.1016/j.jeconom.2005.07.009

Song, J., & Zheng, J. (2015). The application of Grey-TOPSIS method on teaching quality evaluation of the higher education. *International Journal of Emerging Technologies in Learning (iJET)*, *10*(8), 42-45. https://doi.org/10.3991/ijet.v10i8.5219

Shen, B., Han, Y., Price, L., Lu, H., & Liu, M. (2017). Techno-economic evaluation of strategies for addressing energy and environmental challenges of industrial boilers in China. *Energy*, *118*, 526-533. https://doi.org/10.1016/j.energy.2016.10.083

Stanujkic, D. (2016). An extension of the ratio system approach of MOORA method for group decision-making based on interval-valued triangular fuzzy numbers. *Technological and Economic Development of Economy*, *22*(1), 122-141. https://doi.org/10.3846/20294913.2015.1070771

Stanujkic, D. (2015a). Extension of the ARAS method for decision-making problems with interval-valued triangular fuzzy numbers. *Informatica, 26*(2), 335-355. https://doi.org/10.15388/Informatica.2015.51

Stanujkic, D., Zavadskas, E.-K., Brauers, W.-K.-M, & Karabasevic, D. (2015b). An extension of the MULTIMOORA method for solving complex decision-making problems based on the use of interval-valued triangular fuzzy numbers. *Transformations in Business & Economics, 14*(2B), 355-375. https://doi.org/10.15388/Informatica.2015.51

Stefano, N. M., Casarotto Filho, N., Vergara, L. G. L., & da Rocha, R. U. G. (2015). COPRAS (complex proportional assessment): State of the art research and its applications. *IEEE Latin America Transactions*, *13*(12), 3899-3906. https://doi.org/10.1109/TLA.2015.7404925

Tamošaitienė, J., Zavadskas, E. K., Liou, J. J., & Tzeng, G. H. (2014). Selecting suppliers in green supply chain management. In *8th International Scientific Conference Business and Management 2014* (pp. 770-776). Vilnius, Lithuania. https://doi.org/10.3846/bm.2014.093

Tavana, M., Momeni, E., Rezaeiniya, N., Mirhedayatian, S. M., & Rezaeiniya, H. (2013). A novel hybrid social media platform selection model using fuzzy ANP and COPRAS-G. *Expert Systems with Applications*, *40*(14), 5694-5702. https://doi.org/10.1016/j.eswa.2013.05.015

Tupenaite, L., Zavadskas, E. K., Kaklauskas, A., Turskis, Z., & Seniut, M. (2010). Multiple criteria assessment of alternatives for built and human environment renovation. *Journal of Civil Engineering and Management*, *16*(2), 257-266. https://doi.org/10.3846/jcem.2010.30

Turskis, Z., Zavadskas, E. K., & Peldschus, F. (2009). Multi-criteria optimization system for decision making in construction design and management. *Engineering Economics*, *61*(1).

Velasquez, M., & Hester, P. T. (2013). An analysis of multi-criteria decision making methods. *International Journal of Operations Research*, *10*(2), 56-66.

Wang, K., Wei, Y. M., & Zhang, X. (2013). Energy and emissions efficiency patterns of Chinese regions: a multi-directional efficiency analysis. *Applied Energy*, *104*, 105-116. https://doi.org/10.1016/j.apenergy.2012.11.039

Xue, Y. X., You, J. X., Zhao, X., & Liu, H. C. (2016). An integrated linguistic MCDM approach for robot evaluation and selection with incomplete weight information. *International Journal of Production Research*, *54*(18), 5452-5467. https://doi.org/10.1080/00207543.2016.1146418

Zavadskas, E. K., Turskis, Z., & Kildienė, S. (2014). State of art surveys of overviews on MCDM/MADM methods. *Technological and Economic Development of Economy*, *20*(1), 165-179. https://doi.org/10.3846/20294913.2014.892037

Zavadskas, E. K., Mardani, A., Turskis, Z., Jusoh, A., & Nor, K. M. (2016). Development of TOPSIS method to solve complicated decision-making problems – An overview on developments from 2000 to 2015. *International Journal of Information Technology & Decision Making*, *15*(03), 645-682. https://doi.org/10.1142/S0219622016300019

Zhang, N., & Choi, Y. (2013a). Total-factor carbon emission performance of fossil fuel power plants in China: A metafrontier non-radial Malmquist index analysis. *Energy Economics*, *40*, 549-559. https://doi.org/10.1016/j.eneco.2013.08.012

Zhang, N., Zhou, P., & Choi, Y. (2013b). Energy efficiency, CO2 emission performance and technology gaps in fossil fuel electricity generation in Korea: A meta-frontier non-radial directional distance-function analysis. *Energy Policy*, *56*, 653-662. https://doi.org/10.1016/j.enpol.2013.01.033

Zolfani, S. H., Pourhossein, M., Yazdani, M., & Zavadskas, E. K. (2018). Evaluating construction projects of hotels based on environmental sustainability with MCDM framework. *Alexandria Engineering Journal*, *57*(1), 357-365. https://doi.org/10.1016/j.aej.2016.11.002