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To cite this article: Abbas Mardani, Ahmad Jusoh, Katarzyna Halicka, Joanna Ejdys, Andrzej Magruk & Ungku Norulkamar U. Ahmad (2018): Determining the utility in management by using multi-criteria decision support tools: a review, Economic Research-Ekonomiska Istraživanja

To link to this article: <https://doi.org/10.1080/1331677X.2018.1488600>



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Published online: 24 Nov 2018.



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## Determining the utility in management by using multi-criteria decision support tools: a review

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### ABSTRACT

The multiple criteria decision-making (MCDM) utility-determining techniques are considered to be new development techniques that have been recently presented, extended and used by some scholars. In the current work, an attempt is made to present a systematic review of methodologies and applications of the MCDM utility-determining techniques discussed in recent years. The researchers reviewed 86 papers, describing the use of the MCDM utility-determining techniques, which were published in the period 2004–2015 in more than 42 scientific journals. They mainly refer to the area of management and are extracted from online databases, such as Web of Science, Scopus and Google Scholar. According to the classification used by the researchers, the papers were grouped based on the five main MCDM utility-determining techniques, including stepwise weight assessment ratio analysis (SWARA), the weighted aggregated sum product assessment (WASPAS), the additive ratio assessment (ARAS), the method of complex proportional assessment (COPRAS), multi-objective optimisation by ratio analysis (MOORA) and MULTIMOORA (MOORA plus a full multiplicative form). Furthermore, the papers were categorised taking into account their authors, publication date, journal name, the technique and method used, research objectives, research gap and problem, solution and modelling and, finally, the results and findings. The results of this study show that, in 2013, scholars published more papers on the MCDM utility-determining techniques than in other years. It is also worth noting that a group of COPRAS methods (COPRAS-Grey and COPRAS-Fuzzy) was ranked number one among the methods used in this area. With regard to journals, the *Journal of Civil Engineering and Management* was ranked first in the list of journals, which contributed to this review.

### ARTICLE HISTORY

Received 13 June 2016  
Accepted 22 June 2017

### KEYWORDS

ARAS; COPRAS;  
management; MCDM;  
MOORA and MULTIMOORA;  
SWARA; WASPAS

### JEL CLASSIFICATIONS

C4; C44

## 1. Introduction

In operations research, mathematical modelling and sophisticated statistical analysis have been used for solving a number of business and organisational problems and

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improving a decision-making process. Due to the increasing complexity of the business environment, companies rely on analysis to make decisions, which were formerly based on managers' intuition. Operations research provides the required tools for government agencies and large companies to make better decisions to reduce risks, and to enhance the quality of their performance. Challenges associated with the development of technology and global economy complicated the business environment even more. The operations research based on the advanced software tools and sophisticated mathematical models can help to evaluate all the options available to a firm with respect to possible project outcomes and perform the analysis of risks associated with making particular decisions. The results obtained in these analyses present the complete information, based on which managers can make the required decisions and work out an appropriate policy. As an effective framework, multiple criteria decision-making (MCDM) was widely used to evaluate a finite number of decision alternatives with multiple criteria. It was used in diverse scientific fields, such as business and in solving the problem of sustainability. In solving many real-world problems, it is difficult for decision-makers to precisely assess performance ratings and criteria weight (Hatami-Marbini, Tavana, Moradi, & Kangi, 2013). The fuzzy set of Zadeh (1965) has been found to be particularly suitable for describing the ambiguities when decision options associated with the solution of MCDM problems are evaluated. Various scholars proposed different methods in the framework of multi-attribute utility theory for multi-criteria decision-making in previous years.

Various new MCDM methods and techniques of multi-criteria decision-making were used in a number of projects in different areas, especially in the field of management and engineering projects related to construction management, energy saving, etc. Moreover, some new techniques for using multi criteria analysis (MCA) of particular projects were extended by scholars in previous years. These techniques are as follows: complex determination, which is important for considering qualitative and quantitative characteristics (e.g., complex proportional assessment (COPRAS) method) (Zavadskas, Kaklauskas, Banaitis, & Kvederyte, 2004; Kaklauskas, Zavadskas, Raslanas, Ginevicius, Komka, & Malinauskas, 2006) and the method of multi-objective optimisation by ratio analysis (MOORA) (Brauers & Zavadskas, 2006). The presented techniques had some practical implications; for example, MOORA and COPRAS techniques were applied to multi-attribute evaluation in making road design solutions and to assessing the sustainability of residential areas in Vilnius (Zavadskas, Kaklauskas, Tuskis, & Tamosaitiene, 2008c).

In management and engineering, one of the most persistent problems refers to making optimal decisions in particular situations. For example, in management and engineering, researchers are often faced with different problems associated with the need for making effective decisions. Management and engineering projects are considered to be complex projects associated with situations where robust decisions should be made. These decisions are made at various stages of management and engineering project development. For example, decisions are made at the stage of feasibility study prior to design, procurement and construction stages to identify the viability of the project undertaken by an investor. Decision-making in the field of management and engineering often faces the need to deal with hazardous

phenomena. They include industrial accidents, causing damage to the built property, as well as structural failures, extreme natural phenomena and dangerous human activities. Proper decisions made by architects and civil engineers might reduce the risk posed by the above-mentioned phenomena. Decision-making in this field might be facilitated by applying some formal methods, such as MCDM, as well as discrete or continuous optimisation methods. Most, if not all, decisions are usually made under uncertainty. The failure probability analysis is an effective tool for decision-making on the reliability of structures. The factors referring to decision-making can be identified by using the methods of uncertainty and sensitivity analysis of mathematical model outputs. The sensitivity analysis is crucial for understanding and applying complex mathematical models to the investigation of the reliability problems associated with bearing structures. All the terms, describing the ranking of influence, importance and dominance, are related to uncertainty and sensitivity analysis.

Previous studies were based on methods and techniques offered by the scholars of that time. However, the conducted surveys did not keep up with the changing situation in this field. Therefore, the researchers believe that there is a need for a systematic review of the most important recent studies conducted in the considered area. In addition, the researchers think that there is a need for a comprehensive paper combining the available studies and methods. The presented review attempts to systematically describe some previous studies that employed the considered methods and techniques. In addition, this paper attempts to discuss the exponentially growing interest in the MCDM methods and techniques and provide comprehensive literature on the MCDM methodologies and applications. This paper makes three contributions to this area of study; first, by developing a classification scheme with practical considerations, structurally reviewing the literature with the aim of presenting a guide to these studies of MCDM methods offered by previous scholars, and some recommendations for future studies. Moreover, the current study takes into consideration some new perspectives in reviewing the articles, such as categorisation of the papers based on their authors, publication date, journal name, the technique and method used, research objectives, research gap and problem solution, as well as modelling and, finally, the results and findings. The remaining part of this paper is organised as follows. [Section 2](#) reviews the literature on the decision-making techniques. [Section 3](#) presents the research methodology and the procedure used in the study. [Section 4](#) provides the findings of this review based on the literature describing the application areas, objectives and problems. [Section 5](#) discusses the results based on the research problems. Finally, [Section 6](#) presents the conclusion, limitations of the research and recommendations for future studies.

## **2. Literature review**

### **2.1. Classification of MCDM methods**

The MCDM methods cover a wide range of distinct approaches. The MCDM methods can be classified into two categories: the discrete MCDM or discrete multi-attribute decision-making (MADM) and continuous multi-objective decision-making (MODM) methods (Chauhan & Vaish, 2012; Kahraman & Çebi, 2009; Zavadskas,

Turskis, & Kildiene, 2014c). Recently, hundreds of papers have been published providing information about MCDM methods, their development and application in different fields. This article provides an overview of the publications describing MCDM methods. The study was performed on the Web of Science database, which is a part of Thomson Reuters Web of Knowledge. The 1970s present an important period for many seminal works. The fundamentals of modern MCDM methods were developed in 1950s and 1960s. The research and development of MCDM methods increased during the 1980s and early 1990s, but it seems that the exponential growth of this process continued (Koksalan, Wallenius, & Zionts, 2011). The book by Koksalan et al. (2011) provides a brief history of the development of MCDM methods. It describes the development of this area from ancient to modern times. Mardani, Jusoh, Md Nor, Khalifah, and Zakwan (2015a) and Mardani, Jusoh, and Zavadskas (2015b) grouped MCDM and fuzzy MCDM (FMCDM) tools in a different way. Keeney, Raiffa, and Rajala (1979) formulated the basics of decision with multiple objectives. Hwang, Masud, Paidy, and Yoon (1979) provided a review of the development and applications of MODM methods in a relatively short period of time. Later, Tzeng and Huang (2011) reviewed the MADM methods (simple additive weighting (SAW), technique for order of preference by similarity to ideal solution (TOPSIS), elimination and choice expressing reality (ELECTRE), and the linear programming technique for multidimensional analysis of preference (LINMAP)).

Saaty (1980) published a detailed study of the analytic hierarchy process (AHP). Later, Saaty (1996) published a study of the further development of the analytic network process (ANP) method. Zeleny and Cochrane (1982) published a book dealing with the problem of the compromise theory. Hwang and Lin (1987) published the investigation of group decision-making under multiple criteria. Roy (1996) summarised the information on the ELECTRE group methods. Seminal studies were prepared by Belton and Stewart (2002), Gal, Stewart, and Hanne (1999) and Miettinen (1999). Brauers (2004) published research based on the MOORA and MULTIMOORA (MOORA plus the full multiplicative form) methods. In recent years, the development of hybrid and modular methods has grown in importance. The related studies are performed on the previously developed well-known methods, such as TOPSIS (Hwang & Yoon, 1981), SAW (MacCrimmon, 1968), AHP (Saaty, 1971; Saaty, 1988), ANP (Saaty, 1996), visekriterijumska optimizacija i kompromisno resenje (VIKOR) (Opricovic, 1998; Opricovic & Tzeng, 2002), decision-making trial and evaluation laboratory (DEMATEL) (Fontela & Gabus, 1976), data envelopment analysis (DEA) (Charnes, 1994; Charnes, Cooper, & Rhodes, 1978; Nazarko & Chodakowska 2015), preference ranking organisation method for enrichment evaluations (PROMETHEE) (Mareschal, Brans, & Vincke, 1984), ELECTRE (Roy, 1968; Roy, 1971; Roy, 1978; Roy & Bertier, 1973) and their modifications by applying fuzzy and grey number theory. The relatively recently developed MCDM methods, such as complex proportional assessment (COPRAS) (Zavadskas, Kaklauskas, & Sarka, 1994; Zavadskas & Antucheviciene, 2007; Zavadskas, Kaklauskas, Turskis, & Tamosaitiene, 2008c), additive ratio assessment (ARAS) (Turskis & Zavadskas, 2010a; Turskis & Zavadskas, 2010b; Zavadskas & Turskis, 2010), MOORA (Brauers & Zavadskas, 2006), MULTIMOORA (Brauers & Zavadskas, 2010), stepwise weight assessment ratio

analysis (SWARA) (Kersulienė, Zavadskas, & Turskis, 2010) and weighted aggregated sum product assessment (WASPAS Zavadskas, Turskis, Antucheviciene, & Zakarevicius, 2012a) are being rapidly developed and applied to solve real-life problems.

The related literature covers a number of classifications of MCDM tools with fuzzy theory sets. For example, Peneva and Popchev (2008) stated that if the weights were given as real numbers, the operators, such as weighted arithmetic means (Chiclana, Herrera, & Herrera-Viedma, 1998), ordered weighted maximum (OWMAX) and minimum (OWMIN) (Fodor & Roubens, 1995) and the ordered weighted geometric operator (Chiclana, Herrera, & Herrera-Viedma, 2000) could be applied to the aggregation of fuzzy relations. In the mathematical model, there are operators whose weights do not adequately represent them: Min, Max, MaxMin, gamma and generalised mean (da Costa Sousa & Kaymak, 2001). The idea of using the given weights in this case is offered in Yager (1994). The two other categories proposed by Hwang, Chen, and Hwang (1992) include the ways for finding a ranking based on the degree of optimality, linguistic ranking methods and the comparison function, as well as Hamming distance, proportion to the ideal, fuzzy mean and spread, centroid index, left and right scores and area measurement. The second category contains the methods, employing different ways of evaluating the relative significance of multi-attributes, including analytic hierarchy process, fuzzy simple additive weighting methods, fuzzy outranking methods, fuzzy conjunctive/disjunctive methods and maximin methods. Inuiguchi, Ichihashi, and Tanaka (1990) performed a study of recent developments in fuzzy programming. In their work, they employed such applications as flexible programming, possibilistic programming, possibilistic linear programming with fuzzy goals, possibilistic programming with fuzzy preference relations, possibilistic linear programming using fuzzy max and robust programming.

Based on the relationship among the aggregated arguments, the aggregation operators can be roughly divided into two classes: the operators that consider the dependence of aggregated arguments and those that consider these arguments independently. In the case of the first class, Yager (1988) introduced the ordered weighted averaging (OWA) operator for reordering the arguments prior to their aggregation. This operator motivated Chiclana et al. (2000) and Xu and Da (2002) to propose the ordered weighted geometric (OWG) operator. Yager (2004) used the continuous interval-valued arguments to develop the continuous ordered weighted averaging (C-OWA) operator. Torra (2010) and Torra and Narukawa (2009) developed the hesitant fuzzy sets (HFSs) concept to present the hesitant fuzzy information, which covers the arguments with a set of possible values. It is considered to be an efficient new tool for collecting and representing the arguments under uncertainty, particularly, in the decision-making process. Zhu, Xu, and Xia (2012) investigated the Geometric Bonferroni Means (BMs) combined with hesitant fuzzy information and introduced the hesitant fuzzy geometric BMs (HFGBM). Yu, Wu, and Zhou (2012) developed the generalised hesitant fuzzy BM (GHFBM), with its application in the multi-criteria group decision-making.

The aggregation techniques had a great influence on the MCDM problems, and the aggregation operators were widely applied to MCDM. In a fuzzy environment, Chen and Tan (1994) developed several functions for measuring the extent to which each alternative is suitable with respect to a set of the criteria used in MCDM. Hong and Choi (2000) used the maximum and minimum operations for developing some



approximate techniques to address the MCDM problems. Moreover, the aggregation operators extended to the intuitionistic fuzzy environment of intuitionistic fuzzy sets (IFS) (Atanassov, 1986) play a significant role for basic elements that reflect preference values or judgements of decision-makers. Li (2005) designed several linear programming models and introduced the respective decision-making methods by means of IFSs. Liu, and Wang (2007) proposed a series of score functions to be applied to solving MCDM problems in accordance with the evaluation functions and the intuitionistic fuzzy point operators. Based on the interval-valued IFSs, Chen, Wang, and Lu (2011) offered a method of multi-criteria group decision-making. However, very few studies were focused on the MCDM problems under the hesitant fuzzy environment. Furthermore, in the decision-making process, hesitancy and uncertainty are generally considered as unavoidable problems. To express the evaluation information of decision-makers more objectively, several improved tools, including a fuzzy set (Zadeh, 1965), an intuitionistic fuzzy set (Atanassov, 1986) and a fuzzy multi-set (Miyamoto, Liu, & Kunii, 2000; Yager, 1986), as well as a linguistic fuzzy set (Xu, 2004a; Xu, 2004b) and type-2 fuzzy set (Dubois & Prade, 1980), were offered in the literature.

The MCDM methods can be applied effectively to determining the value and utility degree of management and engineering and establishing the priority order for their implementation (Turskis, 2008). Using these methods, the problem of evaluating a discrete set of alternatives can be examined based on a set of decision criteria. Different criteria represent various dimensions of the alternatives; as a result, they might conflict. For example, in the construction processes, complex decisions, involving a number of conflicting and interactive criteria are analysed. As a result, the MCDM theory was provided with the elements of mathematical statistics and MCDM methodology, considering statistical relations between the developed criteria. In this regard, some scholars in recent years have attempted to develop, extend and present new MCDM methods and techniques, as well as utility-determining approaches.

The present review paper attempts to systematically describe the techniques and methods offered and used by individual scholars (Table 1).

Although previous studies applied various MCDM utility-determining techniques to different fields of management and engineering, such as the construction management, Lin, Chang, and Lin (2011) used the fuzzy analytic hierarchy process (FAHP) and fuzzy Delphi method to evaluate the performance of a knowledge management system (Radziszewski, Nazarko, Vilutiene, & et al. 2016). In the field of equipment and material selection, Ulubeyli and Kazaz (2009) and Akadiri, Olomolaiye, and Chinyio (2013) employed ELECTRE III, FAHP and AHP for selecting pumps and new materials, as well as sustainable materials. In the transportation field, Cheng and Li (2005) ranked railroad projects by using AHP and the artificial neural network (ANN). In the building field, Kahraman and Kaya (2012) and Kaya and Kahraman (2014) integrated multi-attribute utility theory (MAUT), TOPSIS and AHP to evaluate intelligent buildings. In the construction project field, Pinter and Psunder (2013), Gudiene, Banaitis, Podvezko, and Banaitiene (2014) and Antucheviciene, Zakarevicius, and Zavadskas (2010) used M-TOPSIS, TOPSIS and AHP for assessing the projects and evaluating the construction management. In the field of assessing the construction contractor, Nieto-Morote and Ruz-Vila (2012) used F-TOPSIS, while in

**Table 1.** New MCDM methods.

NO.	METHODS AND TECHNIQUES	AUTHOR	PUBLICATION YEAR
1	MOORA	Brauers and Zavadskas	2006
2	COPRAS	Zavadskas, Kaklauskas, and Sarka	1994
3	COPRAS-F	Zavadskas and Antucheviciene	2007
4	COPRAS-G	Zavadskas, Kaklauskas, Turskis, and Tamosaitiene	2008c
5	ARAS	Zavadskas and Turskis	2010
6	ARAS-G	Turskis and Zavadskas	2010b
7	ARAS-F	Turskis and Zavadskas	2010a
8	SWARA	Kersuliene, Zavadskas, and Turskis	2010
9	MULTIMOORA	Brauers and Zavadskas	2010
10	TOPSIS-M	tAntucheviciene, Zakarevicius, and Zavadskas	2010
11	WASPAS	Zavadskas, Turskis, Antucheviciene, and Zakarevicius	2012a
12	COPRAS method for group decision making in an interval-values intuitionis- tic fuzzy environment	Razavi Hajiagha, Hashemi, and Zavadskas	2013
13	WASPAS-IVIF	Zavadskas, Antucheviciene, Hajiagha, and Hashemi	2014a
14	KEMIRA	Krylovas, Zavadskas, Kosareva, and Dadelo	2014
15	WASPAS-F	Zavadskas, Turskis, and Antucheviciene	2015
16	WASPAS-G	Turskis, Zavadskas, Antucheviciene, and Kosareva	2015b
17	IVIF-MULTIMOORA	Zavadskas, Antucheviciene, Hajiagha, and Hashemi	2015c

the field of bidding strategy, Chou, Pham, and Wang (2013) proposed a new bidding strategy by using FAHP and regression-based simulation. Some studies, including the work of Kucukvar, Gumus, Egilmez, and Tatari (2014), employed F-TOPSIS to evaluate the performance to identify the pavement problems. Wang, Yu, Yang, Lin, Lee, and Cheng (2013), Mohammadi, Sadi, Nateghi, Abdullah, and Skitmore (2014), Jaskowski, Biruk, and Bucon (2010) and Safa, Shahi, Haas, and Hipel (2014) used AHP and ANP, FAHP and TOPSIS for selecting the contractor, project managers and the supplier, while Marcic, Ceric, and Kovacevic (2013) employed the AHP approach for selecting a field-testing method. Regarding the evaluation of performance efficiency in semiconductor companies, Hsu (2015) used the VIKOR method. In the field of renewable energy, Ertay, Kahraman, and Kaya (2013) evaluated renewable energy components by using FAHP. Jato-Espino, Castillo-Lopez, Rodriguez-Hernandez, and Canteras-Jordana (2014) published an article where they presented the application of MCDM methods in management and engineering. In this review paper, AHP, TOPSIS, PROMETHEE, VIKOR, ELECTRE, SAW, DEA, as well as the utility theory, COPRAS, ANP, Delphi, Grey systems theory and other methods used in management and engineering were discussed. However, their review only covered publications from 2004 to 2014, while earlier works were not cited. In their paper,



some significant previously published articles including the article by Słowiński (1986) on the problem of application of MCDM methods to planning the water supply system development were mentioned. On the other hand, Skibniewski and Chao (1992) were the first to use the AHP method in management and engineering. However, the processes of conducting, developing, extending and presenting new MCDM methods and techniques could not keep up with the changing situation.

### 3. Research method

Due to the existence of a wide range of applications of the MCDM utility-determining techniques in the real world, there is a strong motivation to categorise these applications in various areas and subareas. This paper reviews the literature to identify the articles which were published in popular journals and those that provided the most important information to practitioners and researchers who attempted to use or investigate the MCDM utility-determining techniques. To this aim, an extensive search aimed at finding the MCDM utility-determining techniques according to the titles, abstracts, keywords and research methodologies of the papers was made. This paper attempts to document the exponentially increased interest in using the MCDM utility-determining techniques and provide a systematic review of the related literature about the MCDM utility-determining technique applications and methodologies.

#### 3.1. Literature search and article eligibility

According to the classification scheme, a reference repository, which includes a total of 86 published papers, describing the use of the MCDM utility-determining techniques (e.g., MOORA, COPRAS, COPRAS-F, COPRAS-G, ARAS, ARAS-G, ARAS-F, SWARA, MULTIMOORA and WASPAS) is presented. The papers are classified according to the publication date, technique and method, research objective, research gap and problem, solution and modelling, as well as the results and findings and the journals' names. The contributions of the current paper are in three areas as follows: enhancing the classification scheme by focusing on practical considerations, structurally reviewing the literature to guide the research on the MCDM utility-determining techniques and identifying related issues for future studies. Moreover, two new perspectives are taken into consideration in reviewing the articles, which include the categorisation of the papers according to the main five techniques and their categorisation based on research criteria.

The researchers targeted two main library databases, such as Scopus, Web of Science and Google Scholar, which cover the journals presenting the MCDM utility-determining techniques. Items considered in the doctoral dissertations, master's theses, textbooks and unpublished papers were not included in this review. For finding 86 papers published in scientific journals, the researchers mainly considered international journals presenting MCDM utility-determining applications. Figure 1 shows the research methodology.

The following sections briefly describe the papers and summarise the topics in the tables based on the techniques used. In each table, the papers are summarised and highlighted according to their introductions, research methods, and the results of investigation.

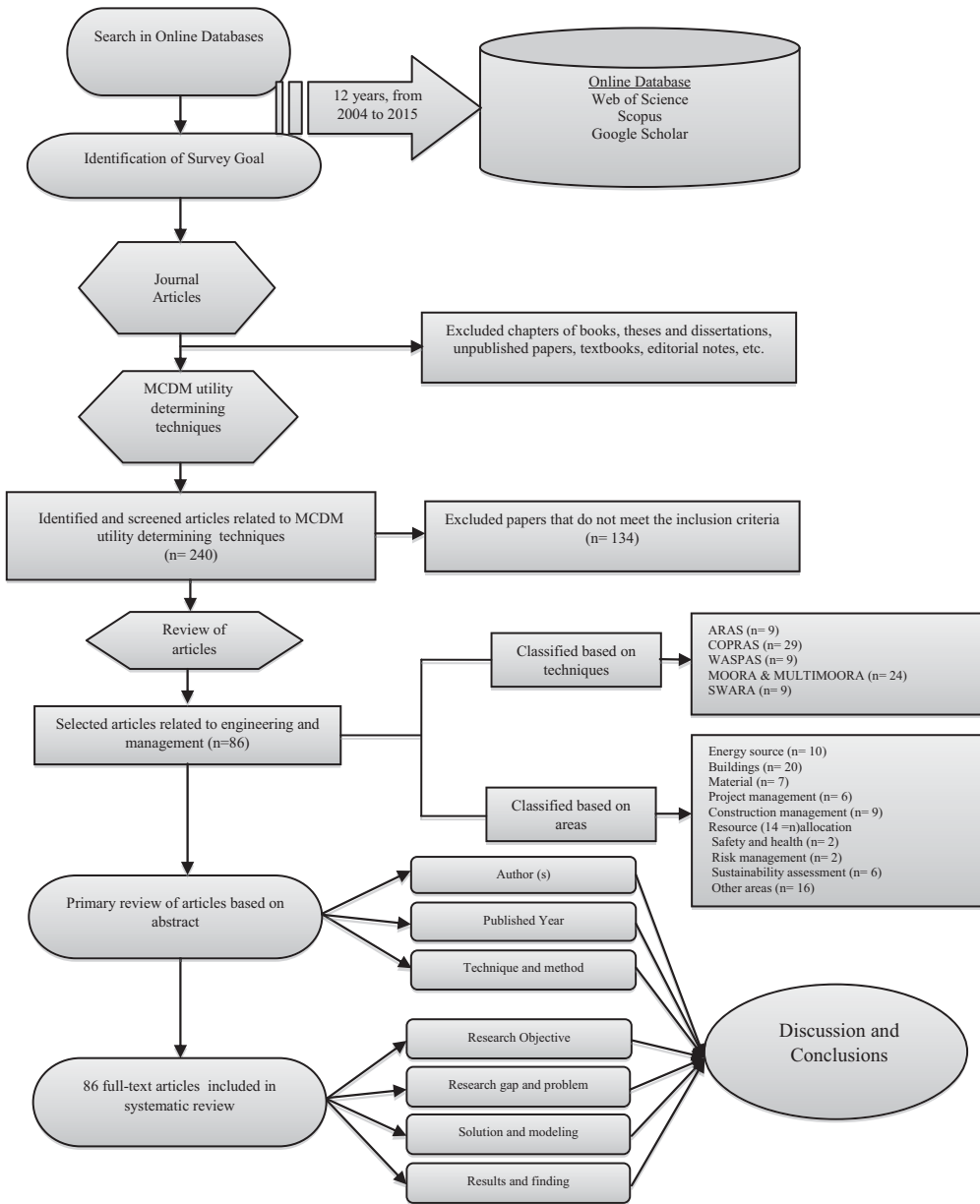


Figure 1. Summary of analyses and procedures used in the study.

#### 4. The obtained results

##### 4.1. Distribution of the MCDM utility-determining techniques

In recent years, research on the MCDM utility-determining techniques has been continued, and many applications of these techniques have been found in several fields. MCDM provides effective decision-making methods for domains where the selection of the best alternative is highly complicated. The current study provides a detailed review of the main trends of considering the MCDM theory and practice. The main

purpose of the review is to identify various MCDM utility-determining techniques used in previous studies and to suggest approaches that could be most effectively applied to identifying the best alternative. MCDM utility-determining techniques were used in many areas, especially in management and engineering. MCDM methods help to choose the best alternatives based on multiple criteria. The best alternative can be determined by analysing the scopes and weights of the criteria and selecting the optimum ones, using any MCDM technique. The current review closely shows the process of enhancing various MCDM utility-determining techniques and their applications in management and engineering and other fields from various perspectives. In total, 86 papers were classified according to the applied five MCDM utility-determining techniques, such as (1) SWARA, (2) WASPAS, (3) ARAS, (4) COPRAS and (5) MOORA and MULTIMOORA (Figure 1).

The sections below provide a systematic review of 86 papers and categorise them into 10 application areas. In the step described below, all papers will be presented in separate tables and each application area will be generally described based on their authors, publication date, the technique and method used, research objective, research gap and problem, as well as solution and modelling, results and findings and the journal's name. In the considered section, the papers were classified based on the applied techniques and then distributed based on the MCDM utility-determining techniques and publication years. The last section presents the papers based on the journals' distribution.

#### **4.2. SWARA**

There are several kinds of MADM methods for criteria weight calculation in the literature. A decision-maker usually finds it more difficult to evaluate different criteria in a decision-making process. In addition, in some methods, the number of calculations is very great, and the accuracy of the methods is not very high. SWARA is a method where experts apply their own implicit knowledge, experiences and information. In addition, it is not considered to be complicated and time-consuming (Zolfani & Sapauskas, 2013). The main feature of the SWARA method is associated with its possibility of estimating the experts' or interest groups' opinions about the significance of the attributes in the process of weight determination (Kersuliene et al., 2010). The first criterion in ranking is considered to be most significant, while the last is least significant (Alimardani, Zolfani, Aghdaie, & Tamosaitiene, 2013). The final ranks are determined by a group of experts based on their average value (Kersuliene & Turskis, 2011). All past and recent studies, where SWARA methodology was used for a particular purpose, are as follows: Kersuliene and Turskis (2011) used it for architect selection; Kersuliene et al. (2010) employed it in rational dispute resolution method selection; Hashemkhani Zolfani, Aghdaie, Derakhti, Zavadskas, and Morshed Varzandeh (2013b) used it in the investigation of success factors of online games based on explorer; Hashemkhani Zolfani, Farrokhzad, and Turskis (2013b) also used it in decision-making on business issues with foresight perspective; Hashemkhani Zolfani and Sapauskas (2013) used it in prioritising the sustainability assessment indicators of an energy system; Alimardani et al. (2013) used it in agile

supplier selection; and Hashemkhani Zolfani and Bahrami (2014) used it in investment-prioritising in high-tech industries. The SWARA technique methodology is presented in Figure 2.

Table 2 presents the studies based on the application of SWARA technique. According to the data presented in this table, a total of nine studies described SWARA techniques that were combined with other techniques and applications. This table shows that one of these papers was published in 2015, three in 2014, four in 2013, one in 2011 and one in 2010. Most of the above-mentioned studies referred to the field of construction management. Table 2 presents all papers, considering the SWARA technique and its application.

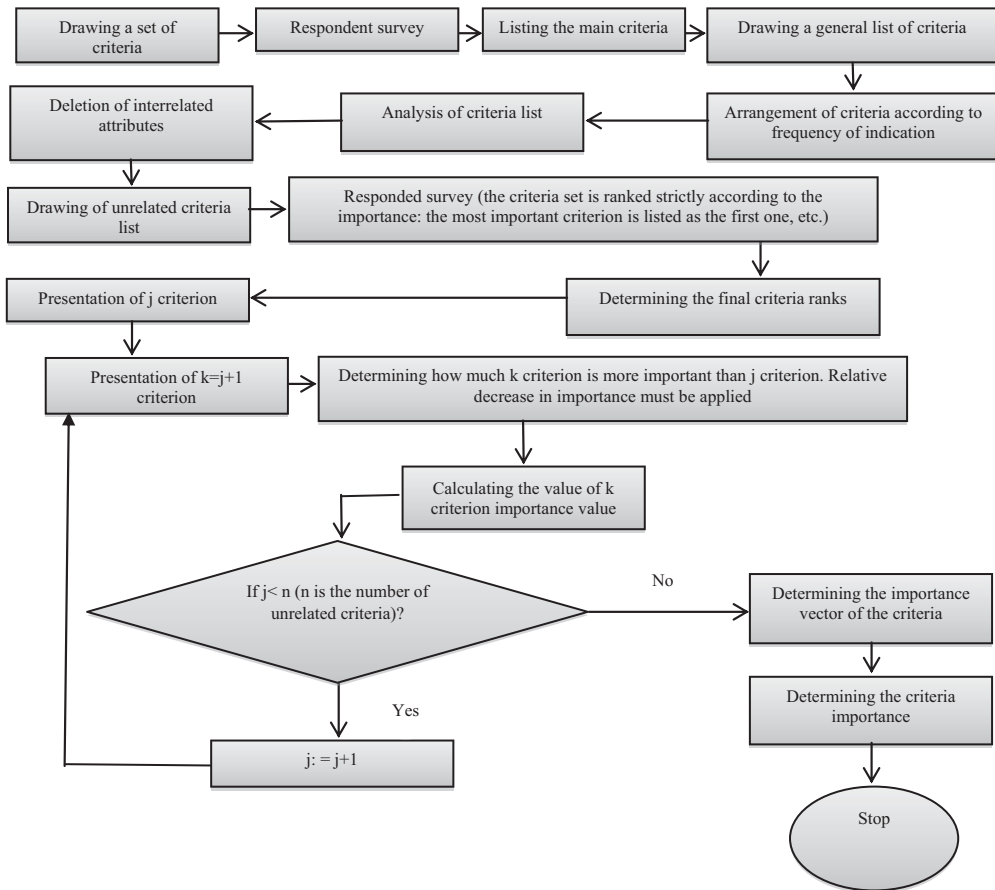
### 4.3. WASPAS

The following section explains the WASPAS method, which is considered to be one of the most recent methods proposed in the literature. This method was designed on two bases, including the weighted product model (WPM) and the weighted sum model (WSM) (Zavadskas et al., 2012a). Zavadskas et al. et al. (2012a) proposed this new method and proved that this aggregated method performs more accurately than other approaches. The comprehensive research conducted recently by using WASPAS method is presented in the following sources: Staniunas, Medineckiene, Zavadskas, and Kalibatas (2013) employed it for ecological-economic assessment of multi-dwelling house modernisation; Zavadskas, Antucheviciene, Sapauskas, and Turskis (2013a) applied it to verification of robustness of methods in assessing the alternative solutions; Dejus and Antucheviciene (2013) used it for assessing health and safety solutions on the construction site; and Hashemkhani Zolfani et al. (2013b) applied it to decision-making with respect to business issues with foresight perspective. The methodology of WASPAS technique is presented in Figure 3.

Table 3 presents the studies where the WASPAS technique was used. Based on the results presented in this table, a total of nine studies used WASPAS technique combined with other techniques and applications. This table shows that three papers were published in 2014 and six in 2013. All of these studies referred to the management and engineering field (see, for example, Bagocius, Zavadskas, & Turskis, 2014). Table 3 presents all papers using the WASPAS technique.

### 4.4. ARAS

Zavadskas and Turskis (2010) proposed the ARAS method, which is a recently formed but easy-to-use and effective MCDM method. This method was applied to solve different decision-making problems. The fuzzy and grey extension of this method referred to as ARAS-Fuzzy (ARAS-F) (Turskis & Zavadskas, 2010a) and ARAS-Gray (ARAS-G) (Turskis & Zavadskas, 2010b) were developed. Only a few of the available studies have been mentioned in the present paper, including Zavadskas, Susinskas, Daniunas, Turskis, and Sivilevicius (2012b), Zavadskas, Turskis, and Tamosaitiene (2010b) and Bakshi and Sarkar (2011). The following steps describe the procedure of solving problems by using the ARAS method: Step 1 – determine the



**Figure 2.** SWARA methodology.

optimal performance rating for each criterion after creating the decision matrix; Step 2 – calculate the normalised decision matrix; Step 3 – calculate the weighted normalised decision matrix; Step 4 – calculate the overall performance index for each alternative; Step 5 – calculation of the utility degree for each alternative; and Step 6 – rank the alternatives and/or select the most efficient (Figure 4).

Table 4 presents the papers that used ARAS technique. Based on the results presented in this table, a total of nine studies used ARAS, ARAS-F and ARAS-G techniques combined with other techniques and applications.

#### 4.5. COPRAS

COPRAS is a method for ranking the alternatives for determining their preference order, which was improved by Zavadskas et al. (1994). They assumed direct and proportional dependences of the priority and utility degrees of the available alternatives in the presence of mutually conflicting criteria. Figure 5 presents the COPRAS technique methodology. This technique focuses on the alternatives' performance by considering various criteria and the corresponding criteria weights. By using the decision

**Table 2.** Distribution of papers based on the SWARA technique.

AUTHOR	TECHNIQUE AND METHOD	RESEARCH OBJECTIVE	RESEARCH GAP AND PROBLEM	SOLUTION AND MODELLING	RESULTS AND FINDINGS
Vafaeipour, Zolfani, Morshed Varzandeh, Derakhti, and Keshavarz Eshkalag (2014)	SWARA and WASPAS	To implement solar projects by applying SWARA and WASPAS techniques	Lack of attention to solar power plants in Middle East countries, such as Iran	Finding 29 quantitative and qualitative criteria based on experts' opinions and literature	Ranking of solar projects in 25 cities of Iran, in which Yazd was ranked first and economical perspective was ranked first in criteria
Hashemkhani Zolfani, Aghdaie, Derakhti, Zavadskas, and Morshed Varzandeh (2013b)	SWARA and WASPAS	The authors applied SWARA and WASPAS to selecting shopping mall location	There is a lack of previous studies considering all criteria for selecting the mall location	The authors of this paper believe that SWARA and WASPAS are powerful techniques for solving these kinds of problems	The results of this study demonstrated that decision criteria can be significant for selecting shopping mall location
Volvaciovas, Turskis, Aviza, and Mikstiene (2013)	SWARA, COPRAS, SAW and TOPSIS	Applied SWARA, COPRAS, SAW and TOPSIS for selecting the strategy of public buildings' retrofit	There is a lack of cost-effective retrofit strategy evaluation	The authors applied MADM techniques for solving this problem	The results obtained in this paper based on nine options and five attributes have shown that the best retrofitting strategy is to perform the construction work at the same stage, using the greatest possible number of workers
Zolfani and Saparauskas (2013)	SWARA	Used SWARA for evaluating energy system sustainability	A need for providing a methodology for sustainable energy generation	Description of decision-making strategies in the considered area is the first goal of this research, and the second goal is decision-making in the field of sustainable energy generation. In this research, the authors proposed a new methodology for solving the major problems	The research has shown that the most important indicator is Social (0.342). Other indicators are ranked as follows: Environmental (0.284), Economic (0.212) and Resource (0.162)
Ruzgys, Volvaciovas,	SWARA-TODIM	Integrated SWARA-TODIM for ranking wall	A need for providing a model for energy	The weights of the criteria were calculated	It can be stated that the final result depends more heavily on

*(continued)*

Table 2. Continued.

AUTHOR	TECHNIQUE AND METHOD	RESEARCH OBJECTIVE	RESEARCH GAP AND PROBLEM	SOLUTION AND MODELLING	RESULTS AND FINDINGS
Ignatavicius, and Turskis (2014)		insulation alternatives in building	consumption by old residential buildings in Europe	after making an expert survey, and the best alternatives were ranked, using the integrated SWARA-TODIM multi-criteria decision-making (MCDM) method	price, duration of work, payback period, energy losses and water vapour diffusion than on the type of façade or present or future insulation requirements
Kersuleni and Turskis (2011)	SWARA and ARAS-F	Used ARAS-F and SWARA for selecting the architect	A need for developing a decision-making approach for solving the problem of multiple information sources, which would incorporate both crisp data and fuzzy data represented as linguistic variables, or triangular fuzzy numbers, into the analysis	In this paper, a FMCDM algorithm, based on the fusion of fuzzy information, as well as the ARAS-F and SWARA techniques, are integrated	The presented case study has shown that this model can be successfully used for choosing the best candidate
Alimardani, Zolfani, Aghdaie, and Tamossaitiene (2013)	SWARA and VIKOR	Used SWARA and VIKOR for supplier selection	Due to a large number of factors, the supplier selection process is a difficult task for every company. Therefore, the supplier selection process can be viewed as a MADM problem	Two MADM methods, including SWARA and VIKOR, were applied to the decision-making process	The results of this article show that the presented method is most practical for supplier alternatives' ranking with respect to the multi-conflicting criteria in agile environment
Hashemkhani Zolfani, and Bahrami (2014)	SWARA-COPRAS	Ranked high tech industries by employing SWARA-COPRAS	A need for focusing on the priority of investment in high-tech industries in Iran	SWARA was used for evaluating and weighting the criteria, while COPRAS was employed for evaluating and ranking the alternatives	The results yielded by the COPRAS method show that Nano Technology is the best high-tech industry to develop in Iran, while Biotechnology is at the second place of importance. Then follows BioMEMS, and Biomedical Engineering is the last according to the priority order

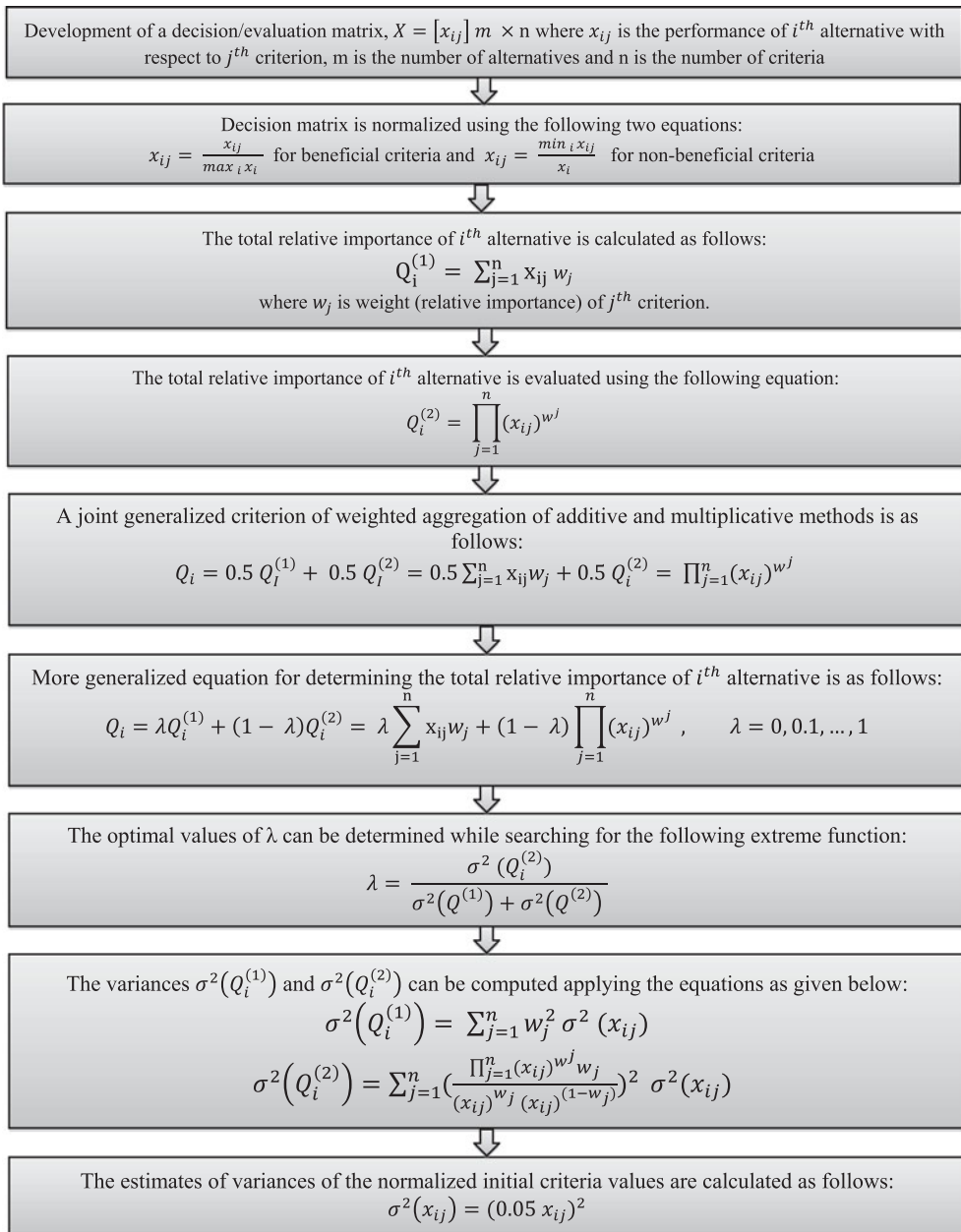
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Table 2. Continued.

AUTHOR	TECHNIQUE AND METHOD	RESEARCH OBJECTIVE	RESEARCH GAP AND PROBLEM	SOLUTION AND MODELLING	RESULTS AND FINDINGS
Kersulieni, Zavadskas, and Turskis (2010)	SWARA	Applied SWARA to evaluating and selecting a rational method of dispute resolution	In order to assess dispute resolution methods from economic, social and other perspectives, it is necessary to apply methods to assessing solutions based on multiple attributes	The SWARA method could be applied to practical implementation of specialised decision support systems and alternative dispute resolution in a virtual environment	It has been proved that successful selection of a rational method for dispute resolution is based on the attribute weight determination by using the SWARA method and the initial decision-making matrix normalised by applying the linear normalisation method



**Figure 3.** Methodology of WASPAS technique.

approach, the direct and proportional dependence of the significance and utility degrees of the alternatives can be evaluated in a system of attributes, weights and the attributes' values. COPRAS attempts to find a solution by using the distance to the ideal solution and the distance to the ideal-worst solution, which are the best and the worst solutions, respectively. The degree of utility is determined by making a comparison between the analysed alternatives and the best one. The values of the utility degree are ranged between 0% and 100% and between the worst and the best



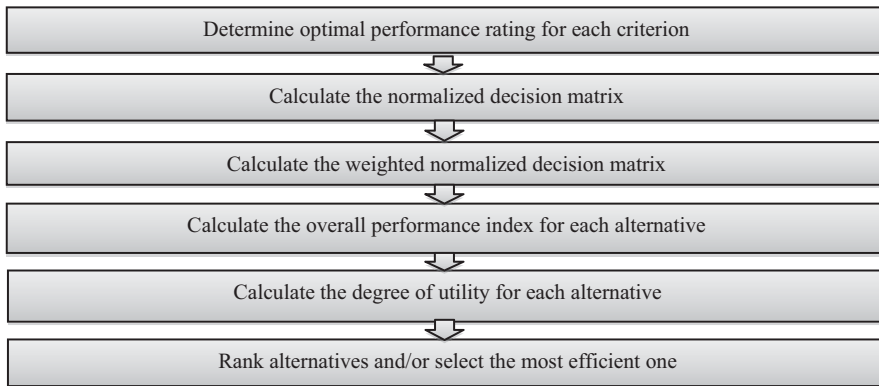
**Table 3.** Distribution of papers based on WASPAS technique.

AUTHOR	TECHNIQUE AND METHOD	RESEARCH OBJECTIVE	RESEARCH GAP AND PROBLEM	SOLUTION AND MODELLING	RESULTS AND FINDINGS
Vafaeipour, Zolfani, Morshed Vazandeh, Derakhti, and Keshavarz Eshkalag (2014)	SWARA and WASPAS	To implement solar projects by applying SWARA and WASPAS techniques	Lack of attention to solar power plants in Middle East countries, such as Iran	Finding 29 quantitative and qualitative criteria based on experts' opinions and literature	In ranking solar projects of 25 cities of Iran, Yazd was ranked first and economic perspective was ranked first among the criteria
Hashemkhani Zolfani, Aghdaie, Derakhti, Zavadskas, and Morshed Vazandeh (2013b)	SWARA and WASPAS	Applied SWARA and WASPAS for selecting shopping mall location	There is a lack of previous studies considering the criteria for selecting the mall location	The authors of this paper believe that SWARA and WASPAS are powerful techniques for solving these kinds of problems	The results of this study have shown that decision criteria can be significant for selecting shopping mall location
Staniunas, Medineckiene, Zavadskas, and Kalibatras (2013)	WASPAS, COPRAS and TOPSIS	Ecological-economic evaluation of dwelling house modernisation by applying WASPAS, COPRAS and TOPSIS	In previous studies, there is a lack of attention to ecological factors in multi-dwelling house modernisation	Three techniques, including WASPAS, COPRAS and TOPSIS, were used for making an ecological-economic assessment of multi-dwelling house modernisation	The results of this study have shown that modernisation can help decrease emissions by about 30%
Zavadskas, Skibniewski, & Antucheviciene (2014b)	WASPAS	The analysis of performance by applying WASPAS to journals of civil engineering	A need to evaluate the progress of scientific journals, such as civil engineering journals	Suggested WASPAS for evaluating a journal's progress	The results of this paper have shown that the ranking order of journals was different when both approaches were used
Zavadskas, Antucheviciene, Sapauskas, and Turskis (2013b)	WASPAS, WPM, WSM and MOORA	Employed WASPAS, WPM, WSM and MOORA for evaluating facades	A need to choose the best design solution for a commercial or public buildings' facades	WASPAS, WPM, WSM and MOORA techniques were applied to selecting the best facades	Four facade alternatives for public and commercial buildings were evaluated considering a set of 12 criteria in the presented case study
Dejus and Antucheviciene (2013)	WASPAS	Employed WASPAS for evaluating health and safety on the construction site	It is emphasised that more investigations should be made to identify the options for improving education and training	The use of the WASPAS technique for assessment and selection of appropriate solutions for occupational safety is suggested	The investigation has revealed that typical solutions for occupational safety are used in the field of road construction; however, they are

(continued)

Table 3. Continued.

AUTHOR	TECHNIQUE AND METHOD	RESEARCH OBJECTIVE	RESEARCH GAP AND PROBLEM	SOLUTION AND MODELLING	RESULTS AND FINDINGS
Siozinyte and Antuheviciene (2013)	WASPAS, COPRAS, AHP and TOPSIS	Used WASPAS, COPRAS, AHP and TOPSIS for solving the problem of tradition continuity and daylighting in reconstructed vernacular buildings	effectiveness of construction workers in the area of health and safety	In order to improve daylighting in the reconstructed building and preserve the features of its vernacular architecture, the AHP was used for weighting the evaluation criteria, and COPRAS, TOPSIS and WASPAS were applied to ranking the available alternative solutions	intended for protecting third persons from accessing dangerous zones next to a construction site rather than for ensuring health and safety of workers  The results show that a rational solution to the problems of daylighting in a reconstructed building and preserving its traditional features of vernacular architecture could be implemented in new glass structures
Bagocius, Zavadskas, and Turskis (2014)	WASPAS	Wind turbine selection using WASPAS	The construction of wind farms is a challenge of crucial importance to Lithuania	MCDM methods represent a robust and flexible tool investigating and assessing possible discrete alternatives evaluated applying the aggregated WSM and WPM method, WASPAS	Calculations were made applying the WASPAS method, which showed that the best type of wind power plant suitable for any conditions is REpower M5 5.0 MW  Wind Turbine
Zavadskas, Antuheviciene, Saparauskas, and Turskis (2013a)	WASPAS, MOORA and MULTIMOORA	Applied WASPAS, MOORA and MULTIMOORA for evaluating the robustness of methods	There is a need to verify the robustness of methods in assessing alternative solutions	The paper employs the innovative, newly developed WASPAS method and the reputed MOORA method, consisting of the ratio system and the reference point approach as well as the full multiplicative form and MULTIMOORA	Based on the results of the research, the conclusion that the newly developed WASPAS method seems to be robust can be confirmed. The validation of the method for real-life applications can also be made



**Figure 4.** Methodology of ARAS technique.

alternatives. The COPRAS method was effectively employed to solve different problems in construction management (Kaklauskas et al., 2006; Kaklauskas, Zavadskas, & Trinkunas, 2007; Zavadskas, Kaklauskas, Turskis, & Tamosaitiene, 2009b), economics, property management, etc. Zavadskas et al. (2008c) described the main ideas related to the COPRAS-G method. The idea of COPRAS-G about the criterion values expressed in intervals is based on real conditions of decision-making and applications of the Grey systems theory (Deng, 1982; Deng, 1988). In COPRAS-G, a stepwise evaluating procedure and ranking of the alternatives is used in terms of the utility degree and significance. In recent improvement of COPRAS, Uzsilaityte and Martinaitis (2010) have compared several criteria of building renovation, which employed energy, environmental and economic criteria, and investigated the effect of renovation in the building's lifecycle; Chatterjee, Athawale, and Chakraborty (2011) used EVAMIX and COPRAS for selecting the materials; Podvezko (2011) used COPRAS and SAW for the comparative analysis of the MCDM approaches; and Chatterjee and Chakraborty (2012) used COPRAS-G for selecting the material in a manufacturing environment. The COPRAS-F method can be employed in cases when the criteria weights and alternative ratings are given in linguistic terms or expressed using trapezoidal or triangular fuzzy numbers.

Table 5 presents the studies where the COPRAS technique is used. Based on the results given in this table, a total of 29 studies employed COPRAS, COPRAS-G, and COPRAS-F techniques combined with other techniques and applications. This table shows that one paper was published in 2015, six in 2014, 12 in 2013, eight in 2012, five in 2011, five in 2010, two in 2009, six in 2008, three in 2007 and one in each year from 2004 to 2006. Table 5 presents all papers that used the COPRAS technique.

#### **4.6. MOORA and MULTIMOORA**

Multi-objective optimisation, also known as multi-criteria or multi-attribute optimisation, is the process of simultaneous optimisation of two or more conflicting attributes (objectives) that are subject to some particular constraints. The MOORA method introduced by Brauers (2004) is a multi-objective optimisation technique, which can be successfully used for solving various types of complex decision-making problems

**Table 4.** Distribution of papers based on the ARAS technique.

AUTHOR	TECHNIQUE AND METHOD	RESEARCH OBJECTIVE	RESEARCH GAP AND PROBLEM	SOLUTION AND MODELLING	RESULTS AND FINDINGS
Zavadskas, Turskis, and Bagocius (2015a)	AHP and ARAS-F	The authors employed AHP and ARAS-F for selecting a deep-water port	Due to uncertain conditions and multitude of requirements, there is a need to develop a deep-water sea port	To solve the site selection problem based on multiple qualitative and quantitative criteria, AHP and ARAS-F were used	The presented method has shown the performance ratio of each alternative to the best alternative
Zavadskas, Turskis, and Vilutiene (2010a)	ARAS	Used ARAS for foundation instalment selection	There is a problem described in previous studies related to selecting the foundation alternative in building redevelopment	The solution of the problem was made by using the ARAS technique	The results of this study have shown that the ARAS technique has a promising future in the field of construction engineering
Sliogeriene, Turskis, and Streimikiene (2013)	ARAS	Employed the ARAS method for selecting the technologies of energy generation	There is no Pareto optimality for analysis and choice of energy generation technologies	For selecting energy generation technologies in Lithuania, two DM techniques including AHP and ARAS were applied	The results of this paper have revealed that, among energy generation technologies, a clear priority is allocated to technologies of biomass
Kaklauskas, Tupenaite, Kanapeckiene, and Naimaviciene (2013)	ARAS	Employed ARAS for evaluating the renovation scenarios of standard housing	There is a problem of selecting efficient renovation measures and scenarios	In order to solve this task, the MCDA (multi-criteria decision analysis) approach is used	The analysis revealed that the alternative 'Project 2' is the best project alternative that can be used as an example of new renovation project development in the cases of renovating the same type of building. Its utility degree is almost 71%
Bakshi and Sarkar (2011)	ARAS and AHP	Evaluation of project selection by using AHP and ARAS	There is a need for MCABased performance for evaluating projects	The AHP is used for analysing the structure of the project selection problem and to assign the weights of the properties and the ARAS method is used to obtain the final ranking and select the best project	The proposed method provides a simple approach of complexity theory to assess the alternative projects and select the best set of projects by using the described integration of the AHP and ARAS methods

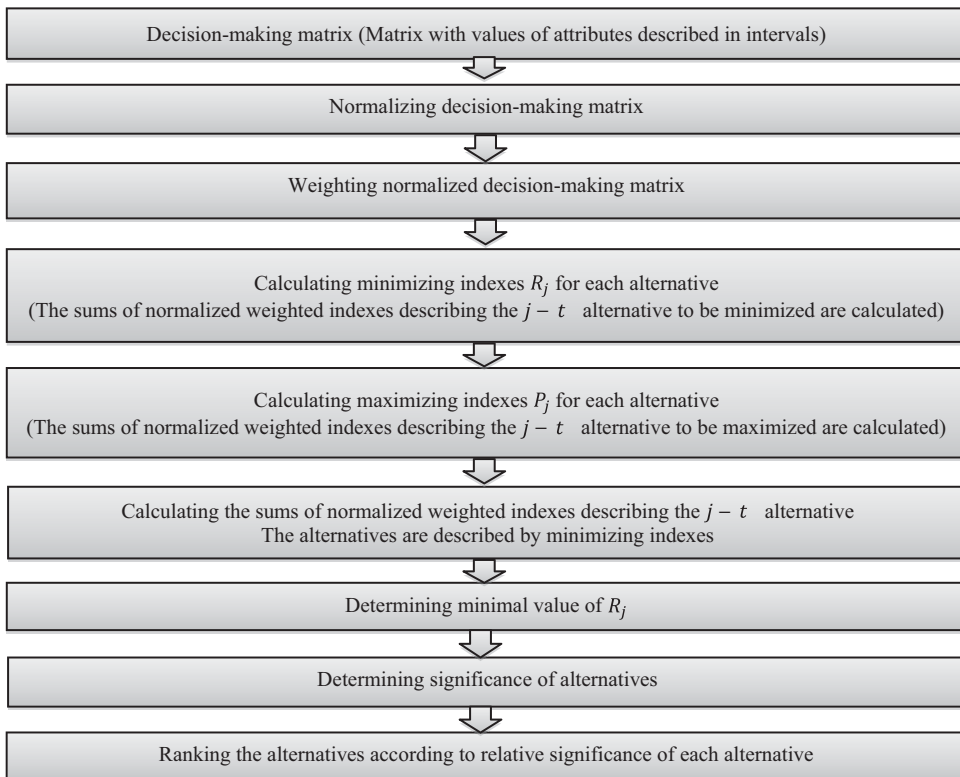
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Table 4. Continued.

AUTHOR	TECHNIQUE AND METHOD	RESEARCH OBJECTIVE	RESEARCH GAP AND PROBLEM	SOLUTION AND MODELLING	RESULTS AND FINDINGS
Balezentiene and Kusta (2012)		Employed ARAS for sustainable fertiliser management	N <sub>2</sub> O, CH <sub>4</sub> , and CO <sub>2</sub> are potential greenhouse gases (GHG), contributing to climate change; therefore, solutions have to be sought to reduce their emission in agriculture	A simulation of multi-criteria assessment of sustainable fertiliser management was carried out based on the ARAS method	It has been found that for supporting soil fertility and reducing anthropogenic GHG emission, causing climate change, the appropriate and environmentally sustainable fertilising rate for semi-natural grassland in central Lithuania should not exceed N60P40K50
Kersulienė and Turskis (2011)	SWARA and ARAS-F	Used ARAS-F and SWARA for selecting the architect	A need to develop a decision-making approach for solving the problem of multiple information sources, which would incorporate both crisp and fuzzy data represented as linguistic variables, or triangular fuzzy numbers, into the analysis	In this paper, a FMCDM algorithm, based on the fusion of fuzzy information, as well as the ARAS-F and SWARA techniques, are integrate.	The presented case study has shown that this model can be successfully used for choosing the best candidate
Balezentis, Balezentis, and Misiunas (2012)	ARAS, TOPSIS and VIKOR	Assessment of financial indicators in Lithuanian sectors by using ARAS, TOPSIS and VIKOR	There is a lack of analyses of the main Lithuanian economic sectors' performance from the perspective of financial ratios	A novel procedure for integrated assessment and comparison of Lithuanian economic sectors on the basis of financial ratios and fuzzy MCDM methods was suggested	The results have shown that the best performing sector is that of forestry and logging
Turskis, Zavadskas, and Kutut (2013)	ARAS-G and AHP	Used ARAS-G, Delphi and AHP for evaluating urban cultural heritage	The need to improve the condition of the built and human environment through efficient decision-making in renovation supported by multi-attribute evaluation	Delphi, AHP and ARAS-G methods, considering different environment factors, as well as stakeholders' needs, were applied to solve this problem	To illustrate the model's efficiency, eight objects of cultural heritage were considered and the results were analysed. The set of eight criteria presented in this paper is not equally effective for all countries





**Figure 5.** Methodology of COPRAS technique.

in the manufacturing environment. The MOORA method starts with a decision matrix showing the performance of different alternatives with respect to various attributes. The MOORA method employs a ratio system, where each performance rating of an alternative with respect to a particular criterion is compared to a denominator, which is representative of all alternatives concerning this criterion (Brauers & Zavadskas, 2012). For this denominator, the best choice is the square root of the sum of squares of each alternative per objective. Different units of performance ratings as well as their range of magnitude are normalised to convert the criteria to dimensionless attributes in the range of 0–1. The MOORA method relies on the reference point approach, implying that the chosen alternative should have the highest composite score which represents the difference between the sum of benefit (SOB) and the sum of non-benefit (SONB) scores.

As mentioned above, the MOORA method was introduced by Brauers and Zavadskas (2006) on the basis of earlier investigations. Brauers and Zavadskas (2010) extended the MOORA method and made it more robust under the name of MULTIMOORA. This feature can be linear utility methods and decision criteria aimed at separating positive and negative criteria to optimise the above-mentioned options. These methods were applied in several studies (Balezentis, Valkauskas, & Balezentis, 2010; Brauers & Ginevicius, 2010; Brauers, Ginevicius, & Podvezko, 2010), which focused on regional studies, international comparisons and investment



**Table 5.** Distribution of papers based on the COPRAS technique.

AUTHOR	TECHNIQUE AND METHOD	RESEARCH OBJECTIVE	RESEARCH GAP AND PROBLEM	SOLUTION AND MODELLING	RESULTS AND FINDINGS
Maiti, Chatterjee, and Chakraborty (2012)	COPRAS-G	To select the best material for a single cutting tool	There are too many types of materials that may be selected for a cutting tool; this paper attempts to select an optimal set of cutting tools to reducing cost and time	Because of the lack of mathematical models and formulations in this area, this paper used the COPRAS-G technique	19 materials for cutting tools were found and ranked by using 10 criteria. Polycrystal, crystal diamonds, powder metal tool steel and oil quenched tool steel were selected as the best options for cutting tools
Tarlochan, Samer, Hamouda, Ramesh, and Khalid (2013)	COPRAS	To find the best performance criteria for designing thin wall structures	There are few studies examining energy absorption response of thin-walled tubes under oblique loads	Due to simplicity in using COPRAS, this paper applied it for solving this problem	Presented three performance criteria, including cost and manufacturing constraints, energy absorption capabilities and crush force efficiency
Nuuter, Lill, and Tupenaite (2015)	COPRAS	To evaluate the sustainability of the Estonian housing market	Increased home ownership rate in Eastern European countries	Because of the reduced time of calculation and ease of use, COPRAS was applied in this study for selecting the countries based on the research objective	Selected the best alternative with respect to housing market sustainability based on six criteria groups in Eastern European countries
Banaitiene, Banaitis, Kaklauskas, and Zavadskas (2008)	COPRAS	To find the best solution for selecting the lifecycle of buildings	There is a problem of selecting the best lifecycle for a building among several alternatives	Developed a new solution to the problem of improving the optimal lifecycle	Presented the approach to determine the lifecycle of a building by using 14 criteria in 85 types of alternatives
Mulliner, Smallbone, and Maliene (2013)	COPRAS	To assess sustainable housing affordability	There are significant challenges in the areas of sustainable development and affordable housing	Applied COPRAS to selecting residential areas	The paper demonstrated that environmental and social criteria affected the affordability stronger than the financial attributes
Zavadskas and Antucheviciene (2007)	F-COPRAS	Used F-COPRAS for ranking the alternatives of a building's regeneration	There is a problem of reusing derelict buildings	Provided the multi-criteria sustainability method for ranking building's regeneration criteria by taking	Identified and ranked 15 criteria for evaluating three rural buildings' regeneration scenarios

(continued)

Table 5. Continued.

AUTHOR	TECHNIQUE AND METHOD	RESEARCH OBJECTIVE	RESEARCH GAP AND PROBLEM	SOLUTION AND MODELLING	RESULTS AND FINDINGS
Zavadskas, Kaklauskas, Banaitis, and Kvederyte (2004)	COPRAS	Used COPRAS for rational credit development and choosing the best housing investment instruments and lenders	A lack of the optimal model for assessing the housing credits in Lithuania	into account the economic benefits Presented a new model based on multi-criteria analysis	Found 10 qualitative and quantitative criteria for developing a new housing credit model in Lithuania
Kaklauskas, Zavadskas, Raslanas, Ginevicius, Komka, and Malinauskas (2006)	COPRAS	Used COPRAS for low-e window selection for public buildings	There are some problems faced by the client choosing low-e windows	The authors stated that COPRAS is the appropriate approach for solving this problem due to precise evaluation of a customer's needs	The results of this study demonstrated how new windows for the main VGTU building were chosen based on COPRAS and 14 criteria
Kaklauskas, Zavadskas, Naimavičienė, Krutinis, Plakys, and Venskuskus (2010)	COPRAS	Applied COPRAS to analyse intelligent built environment to improve the inhabitants' quality of life and to satisfy the inhabitants	There is a problem of defining intelligent built environment in the case of several stakeholders	The COPRAS method was presented for designing a number of the alternative versions of an intelligent built environment	An original model was proposed for a complex analysis of the intelligent built environment
Kanapeckienė, Kaklauskas, Zavadskas, and Seniut (2010)	COPRAS	Used COPRAS for creating a new and original knowledge-based decision support system in construction project management	There are hardly any other studies with similar research goals	The COPRAS technique was presented for defining a new KDSS-CPM system	A new model for comparing and discussing various models of knowledge management proposed by the scholars in the previous years was presented
Nguyen, Dawal, Nukman, and Aoyama (2014)	COPRAS-G and FANP	Used COPRAS-G and FANP TOPSIS-G as well as SAW-G and GRA for selecting a machine tool	There is a need for a comprehensive and simple method for selecting a machine tool based on expert judgements	The FANP and COPRAS-G techniques were integrated due to many quantitative and qualitative attributes in the selection of machine tools	The paper shows that maintenance, productivity, cost and service are the most important factors for selecting machine tools
Rabbani, Zamani, Yazdani-	COPRAS and ANP		There are problems with sustainable performance	A new integrated approach based on BSC, COPRAS	The results of this paper determined the two key (continued)

Table 5. Continued.

AUTHOR	TECHNIQUE AND METHOD	RESEARCH OBJECTIVE	RESEARCH GAP AND PROBLEM	SOLUTION AND MODELLING	RESULTS AND FINDINGS
Chamzini, and Zavadskas (2014)		Employed COPRAS and ANP for evaluating performance based on BSC	of oil-producing companies	and ANP was proposed for evaluating the performance of oil companies	criteria which can greatly improve the performance of oil-producing companies
Staniunas, Medineckiene, Zavadskas, and Kalibatas (2013)	WASPAS COPRAS and TOPSIS	Ecological-economic evaluation of dwelling house modernisation by applying WASPAS, COPRAS and TOPSIS	In previous studies, there is a lack of attention to ecological factors in multi-dwelling house modernisation	Three techniques, including WASPAS, COPRAS and TOPSIS, were used for making an ecological-economic assessment of multi-dwelling house modernisation	The results of this paper show that modernisation can help decrease emissions by about 30%
Lapinskiene and Martinitaitis (2013)	COPRAS	Employed COPRAS for building envelope evaluation	Unfortunately, most authors focus on a small range of optimisation criteria, or choose decision-making methods requiring profound knowledge and experience	The combination of Design Builder and Sima Pro, as well as the COPRAS method, has not yet been mentioned in the literature. The use of these tools and this method does not require great experience, but facilitates the building design process	In this case study, a simple example was presented, but the optimisation criteria showed only a part of all simulation results
Zavadskas, Kaklauskas, Turskis, and Tamosiaitiene (2008c)	COPRAS and COPRAS-G	Used COPRAS and COPRAS-G for selecting effective dwelling house walls	The selection of an effective alternative of external building walls from a vast number of the available alternatives is an important problem in project management	This paper considers the application of grey relational analysis to defining the utility of an alternative and a multi-criteria method (COPRAS-G) is proposed	The results show that this method can be employed as an effective decision aid in multi-attribute selection
Popovic, Stanujkic, and Stojanovic (2012)	COPRAS and COPRAS-G	Selected the investment project by applying COPRAS and COPRAS-G	There is a need for selecting one or more investment projects based on the criteria of financial analysis	The alternative projects' performances were expressed using crisp interval values, and then the best project was selected from the available ones by applying	The results of the work show that financial indicators are satisfactory and the project is exposed to the least risk, which means that the worth and risk

(continued)

Table 5. Continued.

AUTHOR	TECHNIQUE AND METHOD	RESEARCH OBJECTIVE	RESEARCH GAP AND PROBLEM	SOLUTION AND MODELLING	RESULTS AND FINDINGS
Medineckiene and Bjork (2011)	COPRAS, AHP SAW and MEW	Used COPRAS, AHP SAW and MEW for determining the renovation measures suitable for building owners	There is a need to present the appropriate methods of determining the effects and investment costs of a number of renovation measures aimed at improving energy efficiency	the COPRAS and COPRAS-G methods By applying SAW, MEW and COPRAS, the preferences of building owners regarding the renovation measures were studied	combination of project C lies above the project investment frontier The results obtained show the necessity of informing the dwellers about the energy consumption problem and to make them more motivated with respect to their needs, taking into account the problem of global warming
Simanavičienė, Liaudanskiene, and Ustinovichius (2012)	COPRAS, SAW and TOPSIS	Used COPRAS, SAW and TOPSIS to provide a new method for selecting a construction project based on its structural, safety and technological solutions	In order to prevent accidents and occupational diseases, and to improve productivity and job satisfaction of employees, it is necessary to take measures ensuring safety on the construction sites	The authors recommended using MADM methods for quantitative evaluation of each alternative, based on which the ranking of the alternatives could be made to solve the problem	The authors evaluated the complexity of the algorithm of the proposed synthesis decision method (SYMAD-3) and compared it with the complexity of the algorithms of multi-stage synthesis methods proposed by other authors A case study demonstrated that contemporary environmental aspects are of little importance when designing structural systems
Tamosaitiene and Gauditis (2013)	COPRAS	Assessed the structural system of a high-rise building structure by using COPRAS	At the design stage of a structural system, designers often fail to apply various principles of sustainability. There is a need to develop a decision-making method that would simultaneously take into account the impacts of both the cost and the environment There are problems of day-lighting and tradition	The authors of the research concluded that the COPRAS-G method was appropriate for assessing structural systems of high-rise buildings In order to improve day-lighting in the	The results show that a rational solution to the
WASPAS COPRAS; AHP and TOPSIS	Used WASPAS COPRAS, AHP and TOPSIS for solving the				(continued)



Table 5. Continued.

AUTHOR	TECHNIQUE AND METHOD	RESEARCH OBJECTIVE	RESEARCH GAP AND PROBLEM	SOLUTION AND MODELLING	RESULTS AND FINDINGS
Siozinyte and Antucheviciene (2013)		problems of tradition continuity and daylighting in reconstructed buildings	continuity in a reconstructed vernacular building	reconstructed building, and preserve the features of its vernacular architecture, the authors used the AHP for weighting the criteria and COPRAS, TOPSIS and WASPAS for ranking the available alternative solutions	problems of daylighting in a reconstructed building and preserving its traditional features of vernacular architecture could be implemented in new glass structures
Barysiene (2012)	COPRAS-G	Used COPRAS-G for evaluating the technologies of a container terminal	The objective is the optimisation of the container handling cycle by applying various technologies	For achieving a solution to the problem under consideration, the COPRAS-G decision-making method was selected	The theoretical study has shown that the key elements to the efficient functioning of a container terminal at a port are an adequate terminal area and a proper container handling technology
Hashemkhani Zolfani, and Bahrami (2014)	SWARA-COPRAS	Employed SWARA-COPRAS to rank high-tech industries	There is a need to focus on the priority of investment in high-tech industries in Iran	SWARA was applied to evaluating and weighting the criteria and COPRAS was used for evaluating and ranking the alternatives	The results yielded by COPRAS show that nanotechnology is the best high-tech industry to develop in Iran and is followed by biotechnology (which is at the second place of importance) and BiMEMS, while and Biomedical Engineering is last
Vahdani, Mousavi, Tavakkoli-Moghaddam, Ghodranama, and Mohammadi (2014)	COPRAS-F	Applied COPRAS-F for supplier selection	There is a need for a decision-making method in terms of multiple conflicting criteria, which would integrate the concepts of interval-valued fuzzy sets and compromise programming for the	The proposed interval-valued fuzzy multi-criteria complex proportional assessment (IVF-COPRAS) method aims to fill this gap in the robot selection area	The results illustrate the applicability and suitability of the proposed IVF-COPRAS method for the evaluation and selection problems

(continued)

Table 5. Continued.

AUTHOR	TECHNIQUE AND METHOD	RESEARCH OBJECTIVE	RESEARCH GAP AND PROBLEM	SOLUTION AND MODELLING	RESULTS AND FINDINGS
Chatterjee and Bose (2013)	COPRAS-F	Applied COPRAS-F to selecting a site for the wind farm	selection problems in order to cope with uncertainty and risk and to fulfil the needs of the DMs The wind farm location selection is a complex multi-criteria problem involving criteria that are ambiguous and conflicting in nature	This study is focused on the applicability of COPRAS-F as a strategic decision-making tool to handle group decision-making problems, such as wind farm location selection	A case study is presented to demonstrate the practicality and effectiveness of the methodology, according to which location L4 is ranked first
Adhikary, Bose, and Mitra (2014)	COPRAS-G	Used COPRAS-G for determining the most critical failure mode for coal-fired thermal power plants	In order to overcome the limitations of the traditional FMECA, an attempt has been made to estimate the improved criticality rankings	The COPRAS-G method, as a multi-criteria decision-making tool, was applied to evaluate the criticalities of the failure modes (the alternatives)	The analysis shows that the most critical failure mode in the coal-fired thermal power plant is the rupture failure of the straight tube of ECO due to erosion, whereas the least critical failure mode is the rupture failure of the stub of ECO due to welding defects
Zavadskas, Turskis, and Tamosaitiene (2010b)	COPRAS-G and TOPSIS grey	The authors employed COPRAS-G and TOPSIS grey assessment of risk in construction projects	The risk level in construction is very high; therefore, there is a need to identify risks	The ranking of the objects and determination of their optimality were performed by applying the TOPSIS grey and COPRAS-G methods with attribute values determined in intervals	The research results revealed different risk levels of the construction objects
Tupenaite, Zavadskas, Kaklauskas, Turskis, and Seniut (2010)	COPRAS SAW, ARAS and TOPSIS	Used SAW, ARAS, TOPSIS and COPRAS for evaluating the built and human environment	Decision-makers considering the built environment renovation should avoid using methods intended for evaluating a	The widely known multicriteria assessment methods, SAW, TOPSIS and COPRAS, and the newly developed ARAS method	The MCA of the projects assessed by ARAS SAW, and COPRAS techniques yielded the same results. The optimal alternative was the conservation and

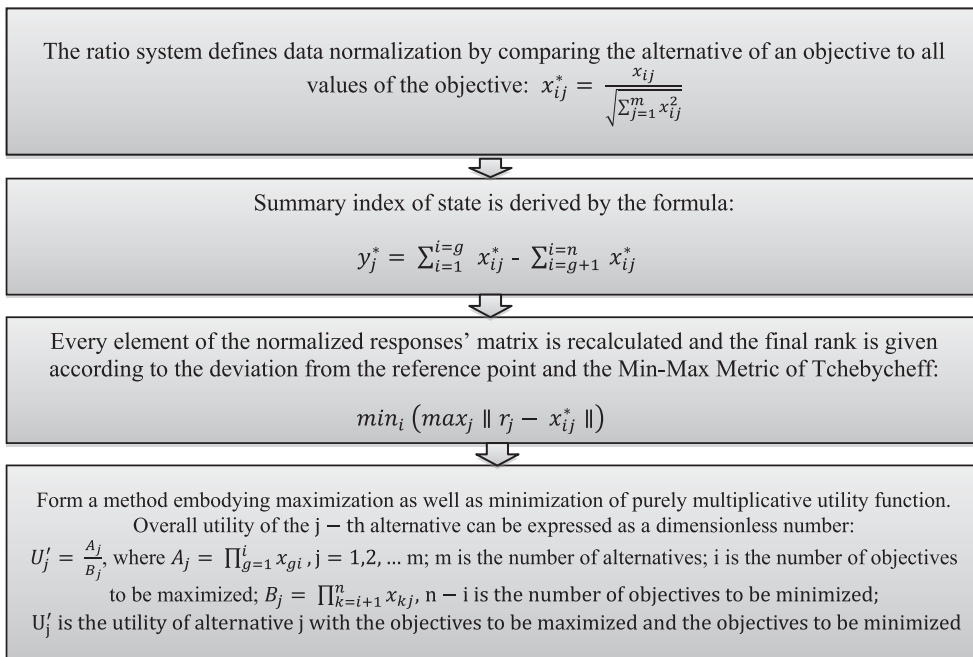
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Table 5. Continued.

AUTHOR	TECHNIQUE AND METHOD	RESEARCH OBJECTIVE	RESEARCH GAP AND PROBLEM	SOLUTION AND MODELLING	RESULTS AND FINDINGS
Uzsilaityte and Martinaitis (2010)	COPRAS	Applied COPRAS to assessing the renovation of a public building	Climate change became a priority issue on the agenda for developing the energy and environmental policy of the European Union. Therefore, there is a need to change the attitude to the evaluation of the renovation benefits of the existing buildings	In this paper, COPRAS was used to determine the best alternative	restoration of Shumen Fortress and the least optimal alternative was the establishment of 'Sofia Arsenal' museum for contemporary art The results of the analysis demonstrated that, in the considered case, the replacement of district heating, mostly based on fossil fuel, with a biomass boiler is most effective in terms of the environment protection and energy saving
Zavadskas, Kaklauskas, Turskis, and Tamosaitiene (2009b)	COPRAS-G	Used COPRAS-G for evaluating project managers	The role of the construction project manager is very important in the process of construction. The construction process is risky and its success largely depends on the choice of the right project manager	This paper considered the application of grey relations methodology to defining the utility of alternatives, and a multi-criteria method of COPRAS-G was offered	The results obtained demonstrate that this method may be used as an effective decision aid in multi-attribute selection



**Figure 6.** Methodology of MULTIMOORA and MOORA techniques.

management. Figure 6 presents the methodology underlying the MULTIMOORA and MOORA techniques.

Table 6 demonstrates the studies performed by using the MULTIMOORA and MOORA techniques. According to the results presented in this table, a total of 24 studies employed MULTIMOORA and MOORA techniques combined with other techniques and applications. Table 6 presents all studies which used the MULTIMOORA and MOORA techniques.

#### **4.7. Distribution of papers based on the area of applications**

In recent decades, research on MCDM has continued and many areas for its application have been found. MCDM provides effective decision-making methods in domains where the selection of the best alternative is very complicated. The current study reviews the main streams of considering the MCDM theory and practice in detail. The main purpose is to identify various MCDM utility-determining applications and approaches in several fields of management and engineering, and to suggest approaches which could be used most robustly and effectively to identify the best alternatives. The MCDM method has been applied to many domains of management and engineering. The MCDM method helps to choose the best alternatives in the presence of multiple criteria, while the best one can be obtained by analysing different scopes and weights of the criteria and the selection of the optimum ones is performed by using any MCDM utility-determining technique. This survey shows the development of various MCDM utility-determining methods and their applications in management and engineering. In total, 86 papers were classified into 10 areas: (1)

**Table 6.** Distribution of papers based on MULTIMOORA and MOORA techniques.

AUTHOR	TECHNIQUE AND METHOD	RESEARCH OBJECTIVE	RESEARCH GAP AND PROBLEM	SOLUTION AND MODELLING	RESULTS AND FINDINGS
Jana, Bairagi, Paul, Sarkar, and Saha (2013)	MOORA	To schedule the priorities in a manufacturing system	New manufacturing systems should provide dynamic task allocation for product scheduling	Used MOORA under Fuzzy MOORA as a simple, reliable and easy to implement technique for solving the investigated problem	Identified and evaluated four criteria for selecting 10 products
Balezentiš and Zeng (2013)	MULTIMOORA	The authors extended the MULTIMOORA method by including type-2 fuzzy sets	Extended MULTIMOORA to include the uncertainty assessments, while previous studies did not pay attention to this problem	Extended the MULTIMOORA by including type-2 fuzzy sets, namely generalised interval-valued trapezoidal fuzzy numbers	The results of the proposed method application demonstrated the possibility of using MCDM techniques for uncertainty assessment
Streimikiene, Balezentiš, Krisciukaitiene, and Balezentiš (2012)	MULTIMOORA and TOPSIS	The ranking of technologies for prioritising sustainable electricity production was performed by employing the MULTIMOORA and TOPSIS techniques	Because the selection of sustainable energy sources involves multiple conflicting objectives, there is a need for developing an MCD support model for determining the sustainable energy policy	The authors of this paper believed that MCDM methods could tackle the energy source problem; therefore, two techniques, including TOPSIS and MULTIMOORA, were applied	The study demonstrated that wood CHP, solar power systems, wind and hydro power were the most sustainable criteria
Balezentiš, Streimikiene, and Balezentiš (2013)	Fuzzy MULTIMOORA	The selection of a sustainable energy crop was made by using fuzzy MULTIMOORA	There is a need for presenting the environmentally compatible and acceptable energy crops for Lithuanian climate.	In the presence of various ambiguous data, Fuzzy MULTIMOORA is a suitable technique for solving the studied problem	Several new crops were identified by employing multiple environmentally compatible key criteria
Kildiene (2013)	MULTIMOORA	Presented a feasibility study of evaluating construction enterprises by the MULTIMOORA technique	In order to ensure better functioning of the internal market for construction products and services, it is important that the legal framework should be clear and predictable and the administrative costs be proportional to the objectives pursued	The decision-making tool MULTIMOORA was suggested for assessing the business development potential of the EU member states	The best conditions for business are in Denmark, United Kingdom, Austria, Ireland, Sweden, Finland, Estonia, Latvia and Cyprus. The states with problems and gaps in their business environment and less-favourable conditions for SMEs include Lithuania, Germany, Portugal, Netherlands, Slovenia, France, Spain, Slovakia and

(continued)

Table 6. Continued.

AUTHOR	TECHNIQUE AND METHOD	RESEARCH OBJECTIVE	RESEARCH GAP AND PROBLEM	SOLUTION AND MODELLING	RESULTS AND FINDINGS
Stankevičienė and Sviderskė (2012)	MULTIMOORA and MOORA	Assessed the country's risk level by using the MULTIMOORA and MOORA techniques	There is a lack of a model for evaluating risk level in the Baltic states	MOORA and MULTIMOORA methods were used for calculating and optimising risk level in the Baltic states	Belgium, while the states with the least-favourable conditions for business are Hungary, Romania, Poland, Bulgaria, Italy, Czech Republic, Greece and Luxembourg
Brauers (2012)	MOORA, MULTIMOORA	Used MOORA and MULTIMOORA for assessing project management	There is a need to develop project management for national economy in search for new projects	The author believed that multi-objective optimisation could cope with different objectives, whereas the objectives had their own units	The system of 12 indicators, having an influence on the country risk, was introduced
Balezentis and Balezentis (2011)	MULTIMOORA	Evaluated the strategic management model by employing MULTIMOORA	There is a need to evaluate the Lisbon Strategy's outcomes and suggesting the guidelines for developing the ongoing Europe 2020 strategy	To assess the efforts of the EU member states in seeking Lisbon goals by applying the MULTIMOORA multi-criteria evaluation method	The findings show that if the simulation exercise for a country with the controlled market economy in search for new projects has no practical consequences, it still provides a learning experience with MULTIMOORA in its triple composition
Brauers and Zavadskas (2006)	MOORA	Proposed MOORA for evaluating the transition of economy	A new method for multi-objective optimisation with discrete alternatives should be proposed	Proposed a new method for multi-objective optimisation with discrete alternatives	The synthesis of proposals for target-setting and transformation methodology resulted in the development of the framework for a strategic management model intended for successful implementation of Europe 2020 strategy

*(continued)*

Table 6. Continued.

AUTHOR	TECHNIQUE AND METHOD	RESEARCH OBJECTIVE	RESEARCH GAP AND PROBLEM	SOLUTION AND MODELLING	RESULTS AND FINDINGS
Kalibatas, Zavadskas, and Kalibatiene (2012)	MAAIA and MOORA	Applied MAAIA and MOORA to the selection of apartments with optimal indoor climate	It is important to pay attention to and evaluate indoor air pollutants	In this work, the MOORA method was applied to MAAIA to assess six apartments	The results presented in this paper show that the proposed method can be used to evaluate the indoor environment and to determine whether it meets the standards
Brauers (2004)	MULTIMOORA	Ranked the economic achievements of the European Union by employing MULTIMOORA	There is a lack of analysis of the construction sector during the crisis in 20 European countries from a macroeconomic perspective	Statistical indicators of the construction sector were used and a multi-objective evaluation method named MULTIMOORA was employed	The results of this paper show that the construction sector is not only characterised by its production but by seven attributes, maximised or minimised, depending on the objectives. Similarly, the economy of a country should be optimised using not only its gross domestic product
Kracka and Zavadskas (2013)	MOORA and MULTIMOORA	Selected MOORA and MULTIMOORA for assessing panel buildings	There is a need to describe the process of effective selection of building elements for renovation, required for achieving energy effectiveness in buildings	Multi-criteria MOORA and MULTIMOORA methods were adapted for solving problems with interval data	The results of this paper show that the proposed method can be used to evaluate building refurbishment and to determine whether it meets the standards
Balezentis and Balezentis (2011a)	MULTIMOORA and DEA	Used MULTIMOORA and DEA for assessing Lithuanian transport efficiency	The assessment of the efficiency of a particular economic sector is of high importance for making strategic decisions at any management level	The MULTIMOORA method can be employed for evaluating transport sector efficiency	The final ranks provided by MULTIMOORA show that the transport sector was operating most effectively in the period of 2004–2008, whereas it exhibited relative inefficiency throughout 1996–1998
Chakraborty (2011)	MOORA	Applied MOORA to robot selection	There are challenges of global competitiveness. Therefore, manufacturing	The authors of the paper applied an almost new MODM method (MOORA) to	Six illustrative examples were considered to demonstrate the application of this

*(continued)*

**Table 6.** Continued.

AUTHOR	TECHNIQUE AND METHOD	RESEARCH OBJECTIVE	RESEARCH GAP AND PROBLEM	SOLUTION AND MODELLING	RESULTS AND FINDINGS
Gadakh, Shinde, and Khemnar (2013)	MOORA	Applied MOORA to solving the optimisation problem in welding	companies face the problems of selecting the appropriate manufacturing strategies now  There is a need to optimise the parameters of the welding process	solve various decision-making problems frequently encountered in the real-time manufacturing environment  The MOORA method was applied to solving a multiple-criteria (objective) optimisation problem in welding	method. In all the cases, it could be observed that the top-ranked alternatives exactly matched those earlier derived by other researchers  It could be observed that the top-ranked alternatives matched the alternatives derived by researchers earlier
Brauers (2013)	MOORA	Used MOORA for selecting the best location of a seaport	An approach is needed to localise a seaport in an optimal way based on different indicators, criteria or objectives and taking into account different groups or individuals	The study was aimed at simulating the seaport planning within the framework of multi-objective optimisation	The considered stakeholders were national and local authorities and contributing firms
Sahu, Sahu, and Sahu (2014)	MULTI-MOORA-IVGN	Applied MULTI-MOORA-IVGN to evaluating CNC machine tools	There is a need to explore the relation between the grey number set and MULTI-MOORA methodology with the aim of assessing and benchmarking the preferred CNC candidate machine tool	The authors have found that the application of a grey number set in conjunction with MULTI-MOORA decision methodology is a promising approach from the perspective of assessing and benchmarking the preferred machine tool alternative	The results allowed for determining the most suitable alternative in the process of selecting an efficient CNC machine tool
Stanujkic, Magdalinovic, Milanovic, Magdalinovic, and Popovic (2014)	MOORA	Used MOORA for selecting a grinding circuit (GC)	The selection of the GC design is a very important and a very complex problem	The authors proposed a new multi-criteria decision-making model based on the ratio system as a part of the MOORA method, which helped to appropriately assess the GC designs	According to decision-makers, $\lambda = 0.5$ and the considered GC designs were ranked in the following order: $A3 \succ A1 \succ A2$ . According to the opinions of experts involved in selecting the most appropriate GC design, the obtained ranking order

(continued)



Table 6. Continued.

AUTHOR	TECHNIQUE AND METHOD	RESEARCH OBJECTIVE	RESEARCH GAP AND PROBLEM	SOLUTION AND MODELLING	RESULTS AND FINDINGS
Kalibatas and Turskis (2008)	MOORA	Used MOORA to evaluate inner climate in a building	At the time, when the demands of customers for quality construction are growing, the problem of evaluating the inner climate in a building and analysing it from various perspectives becomes particularly important	By using the MOORA method, the best alternative was chosen from the available options	realistically reflects their applicability The evaluation data obtained by using the MOORA method may be used in determining the market value of particular apartments or flats in Lithuania as well as in other countries
Moravej and Afshar (2014)	MULTIMOORA	Used MULTIMOORA for planning optimisation	Recently, intelligent buildings have received more attention and it seems that microgrids will play a significant role in the future smart power distribution system	MULTIMOORA and AHP approaches are suggested for making the selection among various microgrid planning options	The final ranking of the plans was made considering the uncertainty of demand. Three loading conditions were considered to be high, medium and low
Balezentis and Balezentis (2011b)	MULTIMOORA	Used MULTIMOORA for evaluating farming efficiency in the European Union	There is a need to evaluate economic sector efficiency, which is of great importance for making strategic decisions at any management level	The EU member states were ranked according to the criteria system by using the MULTIMOORA method	The EU member states were divided into three groups encompassing high-, medium- and low-performing states. The high-performing group included the Netherlands, Malta, Denmark, Italy, Belgium, Cyprus, Germany, Sweden and France. The low-performing group consisted of Lithuania, Romania, Slovakia, Slovenia, Portugal, Estonia, Ireland, Latvia and Bulgaria
Balezentis, Balezentis, and Brauers (2011)	MULTIMOORA	Applied MULTIMOORA to well-being optimisation	Well-being is of crucial importance for both the individuals and society as	Used MULTIMOORA for approaching the objective of societal well-being	It was revealed that Ireland, the Netherlands, Denmark, Austria, France, Cyprus,

(continued)



Table 6. Continued.

AUTHOR	TECHNIQUE AND METHOD	RESEARCH OBJECTIVE	RESEARCH GAP AND PROBLEM	SOLUTION AND MODELLING	RESULTS AND FINDINGS
Brauers and Zavadskas (2010)	MULTIMOORA and MOORA	Used MULTIMOORA and MOORA for selecting a project management scenario	The countries of Central and Eastern Europe moved from a previously centrally planned economy to a modern transition economy with a strong market. This paper proposes project management as a response to the transition challenge	MOORA and MULTIMOORA, assisted by the ameliorated nominal group and Delphi techniques, satisfy the study conditions, although in a theoretical way	Finland, Germany and Belgium achieved the highest level of well-being by 2009. At the other end of the spectrum, Czech Republic, Lithuania, Slovakia, Bulgaria, Poland, Hungary, Estonia, Latvia and Romania, considered to be the countries with the lowest well-being, could be found It should be emphasised that satisfying the seven conditions denotes a theoretical goal to be reached
Zavadskas, Antuchevičienė, Saparauskas, and Turskis (2013a)	WASPAS, MOORA and MULTIMOORA	Applied WASPAS, MOORA and MULTIMOORA to evaluating the robustness of methods	There is a need to verify the robustness of methods in assessing the alternative solutions	The paper employs the innovative, newly developed WASPAS method and the reputed MOORA method consisting of the ratio system and the reference point approach, as well as the full multiplicative form and MULTIMOORA	Based on the results of the research, the conclusion that the newly developed WASPAS method seems to be robust can be confirmed. The validation of the method for real-life applications can also be made

energy source, (2) buildings, (3) material, (4) project management, (5) construction management, (6) resource allocation, (7) safety and health, (8) risk management, (9) sustainability assessment and (10) other areas. Regarding the MCDM utility-determining techniques and methods, the results given in this [Figure 1](#) show that; previous scholars published more papers in the fields related to buildings than in other application areas. The information on other application areas is provided in [Figure 7](#).

#### **4.8. Distribution of papers based on MCDM techniques**

[Figure 8](#) gives the frequency of use of popular MCDM utility-determining techniques, including SWARA, WASPAS, COPRAS, MOORA, MULTIMOORA and ARAS.

#### **4.9. Distribution of papers based on the journals of their publication**

The results presented in [Table 7](#) give more than 42 scientific journals and conference publications using the considered MCDM utility-determining techniques.

Based on the research findings, the *Journal of Civil Engineering and Management* was ranked first among the journals presented in this table, while *Technological and Economic Development of Economy* was ranked second and *Procedia Engineering* third among 42 journals considered in the work. The information about other journals is presented in [Table 7](#). Other information related to the distribution of journals is given in [Table 7](#).

#### **4.10. Distribution of papers based on the publication year**

[Figure 9](#) presents important evidence based on the frequency of distribution in terms of the year of publication. The results show that, from 2004 to 2015, the information about using the MCDM utility-determining tools and approaches presented by scholars has grown considerably. According to the findings of this section, the use of these tools and approaches in 2011 was mentioned in 21 papers, and their number increased to 24 papers in 2013. The use of MCDM utility-determining tools and approaches has been increasing every year.

Another interesting result in this table refers to the year 2013, when the MCDM utility-determining tools and techniques were used in the studies more often than in other years. This year shows the highest number of such publications, reaching 24. Accordingly, it can be noted that researchers use the MCDM utility-determining tools and approaches in their studies referring to different fields and categories, and it can be predicted that in the upcoming years their application will also increase. However, in 2014 and 2015, the number of publications decreased.

### **5. Discussion**

This study attempted to review the papers on using the MCDM utility-determining techniques published in the period of about 12 years (i.e., 2004–2015) in popular international journals accessible in databases such as Scopus, Web of Science and

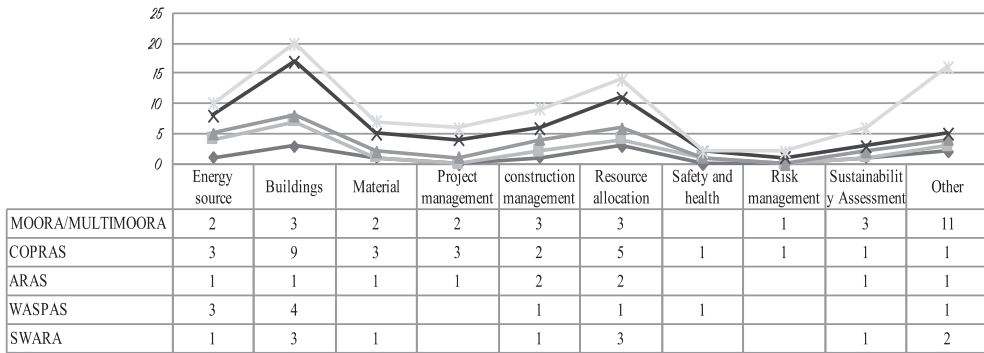


Figure 7. The distribution of papers based on application areas.

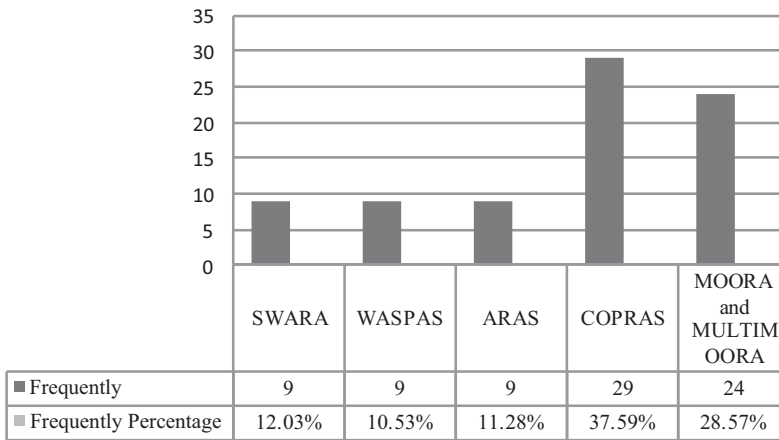


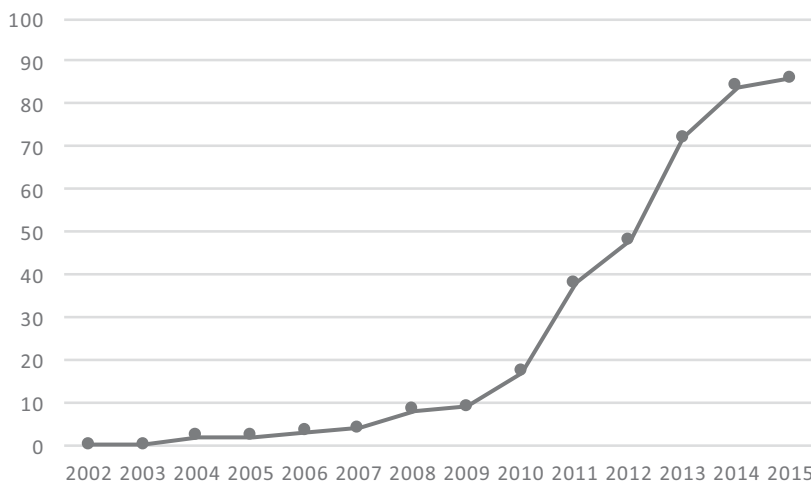
Figure 8. Distribution of papers based on MCDM utility-determining techniques.

Google Scholar. The first aim of this paper was to systematically review the conducted studies, based on using the MCDM utility-determining techniques, such as SWARA, WASPAS, COPRAS, MOORA, MULTIMOORA and ARAS, and which have been published in recent years. To this end, in the first step, a total of 86 published papers about MCDM utility-determining techniques were systematically and carefully chosen and summarised based on the title, abstract, introduction, research method and conclusion. In the next step, according to the predefined objectives of this study, the papers related to the MCDM utility-determining techniques were categorised. In addition, the researchers attempted to choose the papers describing the use of these techniques in engineering and management. The results of this review paper have shown that, in 2013, these techniques were employed by scholars in various inter-related fields of engineering and management (Figure 9). In addition, it has been found that, in terms of the frequency of using the MCDM utility-determining techniques, the COPRAS methods, including COPRAS-G and COPRAS-F, were applied more often than other techniques (Figure 7). Additionally, several international journals, making a total of 42 international journals from three popular databases, including Web of Science, Scopus and Google Scholar, were considered in the current review paper. The *Journal of Civil Engineering and Management* was ranked first among the

**Table 7.** Distribution of papers based on the journals of their publication.

NUMBER	NAME OF JOURNAL	FREQUENCY
1	<i>Journal of Civil Engineering and Management</i>	10
2	<i>Procedia Engineering</i>	5
3	<i>Technological and Economic Development of Economy</i>	6
4	<i>Journal of Business Economics and Management</i>	1
5	<i>Inžinerinè ekonomika – Engineering Economics</i>	2
6	<i>Transport</i>	2
7	<i>Expert Systems with Applications</i>	4
8	<i>International Journal of Strategic Property Management</i>	2
9	<i>Archives of Civil and Mechanical Engineering</i>	3
10	<i>The 7th International Scientific Conference Business and Management</i>	1
11	<i>The International Journal of Advanced Manufacturing Technology</i>	3
12	<i>Economic Computation and Economic Cybernetics Studies and Research</i>	1
13	<i>Informatica</i>	1
14	<i>Journal of Environmental Engineering and Landscape Management</i>	1
15	<i>Renewable and Sustainable Energy Reviews</i>	2
16	<i>Omega</i>	2
17	<i>Automation in Construction</i>	1
18	<i>Energy and Buildings</i>	1
19	<i>Computer Modelling and New Technologies</i>	1
20	<i>Annals of Operations Research</i>	1
21	<i>Journal of Manufacturing Systems</i>	1
22	<i>Energy Procedia</i>	1
23	<i>Decision Science Letters</i>	1
24	<i>Engineering Applications of Artificial Intelligence</i>	1
25	<i>Building and Environment</i>	1
26	<i>International Journal of Information Technology &amp; Decision Making</i>	1
27	<i>Information technology and control</i>	1
28	<i>Energy Conversion and Management</i>	1
29	<i>Czech Economic Review</i>	1
30	<i>European Journal of Operational Research</i>	1
31	<i>20th International Conference/Euro Mini Conference on Continuous Optimization and Knowledge-Based Technologies</i>	1
32	<i>Applied Soft Computing</i>	1
33	<i>Materials &amp; Design</i>	1
34	<i>International Journal of Multidisciplinary Sciences and Engineering</i>	1
35	<i>Thin-Walled Structures</i>	1
36	<i>Land Use Policy</i>	1
37	<i>Serbian Journal of Management</i>	1
38	<i>Theory and Application</i>	1
39	<i>The Scientific World Journal</i>	1
40	<i>Žemès ūkio mokslai</i>	1
41	<i>International Journal of Quality &amp; Reliability Management</i>	1
42	<i>Grey Systems: Theory and Application</i>	1

considered journals in terms of using these techniques. The *Journal of Technological and Economic Development of Economy* was ranked second and *Procedia Engineering* third among the 42 considered journals. Most of the highly ranked journals in the current review were published by Taylor & Francis Group. The results obtained in this study are presented in [Table 7](#).



**Figure 9.** Cumulative distribution of the publication years.

## 6. Concluding remarks

In selected techniques supporting process of management such as decision-making, fuzzy applications and theories, as well as different modelling techniques were offered and a number of suitable approaches were provided for modelling decision-aiding. The researchers focused on developing the alternatives to consider the complexity of the process. Choosing a problem solution approach and a model is associated with the actors involved in the process of decision-making, the desired goals, the available information, time, etc. The most important advantage of the MCDM techniques refers to their capability of addressing the problems which are marked by conflicting interests. Using these techniques, practitioners are able to solve problems that cannot be solved using the common optimisation models. This review paper is mainly focused on the overview of the applications of the MCDM utility-determining techniques, e.g., recent developments of these models of multi-criteria decision analysis. These techniques are being increasingly employed for evaluating the alternatives as well as for comparative analysis. Moreover, a number of significant concepts not addressed in previous studies are discussed. The researchers provided a systematic review of MCDM utility-determining techniques, including SWARA, WASPAS, COPRAS, MOORA, MULTIMOORA and ARAS, where the papers were classified into five different types.

The results presented in this literature review have shown that engineering and management is an area most appropriate for using the MCDM utility-determining techniques. The researchers have shown that there is a great number of MCDM utility-determining techniques, and that several of these techniques had been used to solve problems related to engineering and management. The selection among the available MCDM utility-determining techniques can be considered a multi-criteria problem. In the current review, the researchers attempted to show the application of several MCDM utility-determining techniques to solving engineering and management problems. All the papers examined by the researchers considered different aspects of engineering based on different criteria. Moreover, this study confirms that

the MCDM utility-determining techniques can help decision-makers and stakeholders to overcome some inherent uncertainties of engineering and management decision-making. Furthermore, it can be considered that environmental, economic, technological and social criteria, as well as the total cost, political and legislative factors, suppliers' factors, risk economic, technical environmental and social factors, labour expenditures, urban factors, external risk assessment, project risk assessment, quantitative and qualitative criteria, price, energy source, materials, labour, skilled labour, energy demand, CO<sub>2</sub> emission, investment and exploitation, cost efficiency of energy and power and capital investment, are regarded as the most commonly used criteria in several fields of engineering and management. The criteria weights directly influence the decision-making results, regarding all areas of engineering and management presented in the alternatives. The processes of evaluation and calculation in different fields of engineering and management decision-making are usually based on using the MCDM utility-determining techniques. It is necessary to apply different techniques and approaches to obtain the rankings of the alternatives referring to engineering and management and to ensure the validity of MCDM utility determination. It is believed that the results obtained by various mathematical methods are more rational, and more mathematical methods can contribute to solving engineering and management problems in the future. As long as the criteria and weights are used, MCDM techniques and approaches are appropriate to solve specific decision-making problems in engineering and management, and the MCDM utility-determining techniques can be viewed as a powerful tool for solving the problems in different fields of engineering and management.

Typical engineering problems, such as design, assessment, inspection, maintenance planning and decommissioning may be considered to be decision problems, involving a combination of inherent modelling and statistical uncertainties. In several fields of engineering and management, such as construction management, the construction engineers, as well as engineering, project and asset managers are primarily responsible for the whole decision-making process regarding the expenditure of the infrastructure.

The use of the operations research methods, especially the MCDM techniques, is very important for resolving conflicts between different competing goals in pursuit of the environmental quality, economic prosperity, technological efficiency and social equity. According to the results of the current review, the researchers concluded that previous studies in the fields of engineering and management emphasised the development and application of the multi-criteria methods in the fields of engineering and management to promote the innovations based on the application of these methods, which can facilitate the collaboration of researchers working with the MCDM utility determining techniques in engineering and management and other research areas. Moreover, the current study covered various decision-making problems in engineering and management. These problems can be categorised into the following groups: problems associated with the construction process harmonisation, sustainable urban development, the creation, optimisation and reliability of decision support systems for designing rational technological processes, the application and improvement of the MCDM methods, the problems related to the created expert systems and application

of expert methods in construction, lifetime engineering, complex analysis of a building lifecycle, the creation of the building lifecycle models, risk management assessment, the development of multi-criteria analysis in facilities management, as well as the analysis, modelling and forecasting in construction, equipment selection, enhancing the efficiency of e-commerce systems in construction, using MCDM support systems, material selection and the development of MCDM utility = determining techniques for evaluating the level of economic development, especially, in the member states of the European Union.

This study aimed to review the papers that used the MCDM utility-determining techniques in the field of engineering and management and were published in the period from 2004 to 2015 in 42 international journals accessible in popular databases, such as Scopus, Web of Science and Google Scholar. Moreover, this study attempted to categorise the related papers according to the five main techniques: (1) SWARA, (2) WASPAS, (3) COPRAS (COPRAS-F and COPRAS-G), (4) MOORA and MULTIMOORA, (5) ARAS (ARAS-F and ARAS-G).

In fact, the MCDM methodology has been successfully used in various applications and industrial sectors. However, interdisciplinary and social decision problems should be emphasised. The study of the MCDM anatomy can be developed further. On the other hand, there are many other conventional MCDM techniques which have not yet been studied. Another recommendation for future research refers to the investigation of distinct differences and similarities among the MCDM utility-determining techniques. The insights provided in the present review help channel the research efforts and address the need of practitioners and researchers for an easy reference to MCDM publications and studies.

This study has some major limitations, which can be considered as an object of future studies. First, this review is focused on the use of the MCDM utility-determining techniques rather than on the old MCDM techniques. The articles published at the end of 2014 and in 2015 (if any) have not been included in the present paper because of the limited reporting time. The present review can be expanded for the future studies. Another limitation is that the data were collected from journals, while the examined documents did not include papers, textbooks, doctoral and master's theses and unpublished papers on the MCDM problems. Therefore, in future study, the data can be collected from these sources and the obtained results can be compared with the data obtained and reported in this study. One more limitation is that all the papers were extracted from the journals written in English, which implies that the scientific journals in other languages were not involved in the review. However, the researchers believe that this paper comprehensively reviewed most of the papers published by international journals. Moreover, the current review paper can provide future academic scholars with a better understanding of the MCDM utility-determining techniques. This study can be used by academics and managers as a basis for further research. It can also help practitioners make more appropriate decisions using these techniques and be a guide to scholars, improving the discussed methodologies. The authors of this paper carefully selected and summarised the available papers of several publishers in Web of Science, Scopus and Google Scholar. However, a number of relevant outlets remained beyond the scope of the current study. Therefore, future

researchers will be able to review the papers that are not considered in the current review. Another limitation is associated with the fact that the paper presents a review of numerous works on the problem of using the recently developed MCDM methods published in various journals. However, this review does not cover recent methods discussed in books.

## Disclosure statement

No potential conflict of interest was reported by the author.

## References

- Adhikary, D. D., Bose, G. K., Bose, D., & Mitra, S. (2014). Multi criteria FMECA for coal-fired thermal power plants using COPRAS-G. *International Journal of Quality & Reliability Management*, 31(5), 601–614.
- Akadiri, P. O., Olomolaiye, P. O., & Chinyio, E. A. (2013). Multi-criteria evaluation model for the selection of sustainable materials for building projects. *Automation in Construction*, 30, 113–125.
- Alimardani, M., Zolfani, S. H., Aghdaie, M. H., & Tamosaitiene, J. (2013). A novel hybrid SWARA and VIKOR methodology for supplier selection in an agile environment. *Technological and Economic Development of Economy*, 19(3), 533–548.
- Antucheviciene, J., Zakarevicius, A., & Zavadskas, E. K. (2010). Multiple criteria construction management decisions considering relations between criteria. *Technological and Economic Development of Economy*, 16(1), 109–125.
- Antucheviciene, J., Zavadskas, E. K., & Zakarevicius, A. (2012). Ranking redevelopment decisions of derelict buildings and analysis of ranking results. *Economic Computation and Economic Cybernetics Studies and Research*, 46(2), 37–62.
- Atanassov, K. T. (1986). Intuitionistic fuzzy sets. *Fuzzy Sets and Systems*, 20(1), 87–96.
- Bagocius, V., Zavadskas, E. K., & Turskis, Z. (2014b). Multi-person selection of the best wind turbine based on the multi-criteria integrated additive-multiplicative utility function. *Journal of Civil Engineering and Management*, 20(4), 590–599.
- Bakshi, T., & Sarkar, B. (2011). MCA based performance evaluation of project selection. *International Journal of Software Engineering & Applications*, 2(2), 14–22.
- Balezentiene, L., & Kusta, A. (2012). Reducing greenhouse gas emissions in grassland ecosystems of the central Lithuania: multi-criteria evaluation on a basis of the ARAS method. *The Scientific World Journal*, e511100, 1–11.
- Balezentiene, L., Streimikiene, D., & Balezentis, T. (2013). Fuzzy decision support methodology for sustainable energy crop selection. *Renewable and Sustainable Energy Reviews*, 17, 83–93.
- Balezentis, A., & Balezentis, T. (2011). Framework of strategic management model for strategy Europe 2020: Diachronic analysis and proposed guidelines. *Inžinerinė ekonomika - Engineering Economics*, 22(3), 271–282.
- Balezentis, A., & Balezentis, T. (2011a). Assessing the efficiency of Lithuanian transport sector by applying the methods of MULTIMOORA and data envelopment analysis. *Transport*, 26(3), 263–270.
- Balezentis, A., Balezentis, T., & Misiunas, A. (2012). An integrated assessment of Lithuanian economic sectors based on financial ratios and fuzzy MCDM methods. *Technological and Economic Development of Economy*, 18(1), 34–53.
- Balezentis, A., Valkauskas, R., & Balezentis, T. (2010). Evaluating situation of Lithuania in the European Union: structural indicators and multimooora method. *Technological and Economic Development of Economy*, 16(4), 578–602.
- Baležentis, T., & Baležentis, A. (2011b). A multi-criteria assessment of relative farming efficiency in the European Union Member States. *Žemės ūkio mokslai*, 18(3), 125–135.



- Balezentis, T., Balezentis, A., & Brauers, W. K. (2011). Multi-objective optimization of well-being in the European Union member states. *Ekonomika Istraživanja–Economic Research*, 24(4), 1–15.
- Balezentis, T., & Zeng, S. (2013). Group multi-criteria decision making based upon interval-valued fuzzy numbers: An extension of the MULTIMOORA method. *Expert Systems with Applications*, 40(2), 543–550.
- Banaitiene, N., Banaitis, A., Kaklauskas, A., & Zavadskas, E. K. (2008). Evaluating the life cycle of a building: A multivariant and multiple criteria approach. *Omega*, 36(3), 429–441.
- Barysiene, J. (2012). A multi-criteria evaluation of container terminal technologies applying the COPRAS-G method. *Transport*, 27(4), 364–372.
- Belton, V., Stewart, T. (2002). *Multiple criteria decision analysis: An integrated approach*. New York: Springer.
- Brauers, W. K. M., & Zavadskas, E. K. (2006). The MOORA method and its application to privatization in a transition economy. *Control and Cybernetics*, 35(2), 445–469.
- Brauers, W.K.M. (2004). *Optimization methods for a stakeholder society, a revolution in economic thinking by multi-objective optimization*. Boston: Kluwer Academic Publishers.
- Brauers, W. K. M., & Ginevicius, R. (2010). The economy of the Belgian regions tested with MULTIMOORA. *Journal of Business Economics and Management*, 11(2), 173–209.
- Brauers, W.K.M. (2013). Multi-objective seaport planning by MOORA decision making. *Annals of Operations Research*, 206(1), 39–58.
- Brauers, W.K.M. (2012). Project management for a country with multiple objectives. *Czech Economic Review*, 6(1), 80–101.
- Brauers, W. K. M., Ginevicius, R., Podvezko, V. (2010). Regional development in Lithuania considering multiple objectives by the MOORA method. *Technological and Economic Development of Economy*, 16(4), 613–640.
- 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.
- Brauers, W. K. M., Zavadskas, E. K. (2012). Robustness of MULTIMOORA: A method for multi-objective optimization. *Informatica*, 23(1), 1–25.
- Chakraborty, S. (2011). Applications of the MOORA method for decision making in manufacturing environment. *The International Journal of Advanced Manufacturing Technology*, 54(9–12), 1155–1166.
- Charnes, A. (1994). *Data envelopment analysis: Theory, methodology and applications*. New York: Springer.
- Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, 2(6), 429–444.
- Chatterjee, N., & Bose, G. (2013). A COPRAS-F base multi-criteria group decision making approach for site selection of wind farm. *Decision Science Letters*, 2(1), 1–10.
- 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.
- Chatterjee, P., & Chakraborty, S. (2012). Material selection using preferential ranking methods. *Materials & Design*, 35, 384–393.
- Chauhan, A., & Vaish, R. (2012). Magnetic material selection using multiple attribute decision making approach. *Materials & Design*, 36, 1–5.
- Chen, S.-M., & Tan, J.-M. (1994). Handling multicriteria fuzzy decision-making problems based on vague set theory. *Fuzzy Sets and Systems*, 67(2), 163–172.
- Chen, T.-Y., Wang, H.-P., & Lu, Y.-Y. (2011). A multicriteria group decision-making approach based on interval-valued intuitionistic fuzzy sets: A comparative perspective. *Expert Systems with Applications*, 38(6), 7647–7658.
- Cheng, E., & Li, H. (2005). Analytic network process applied to project selection. *Journal of Construction Engineering and Management*, 131(4), 459–466.

- Chiclana, F., Herrera, F., & Herrera-Viedma, E. (1998). Integrating three representation models in fuzzy multipurpose decision making based on fuzzy preference relations. *Fuzzy Sets and Systems*, 97(1), 33–48.
- Chiclana, F., Herrera, F., & Herrera-Viedma, E. (2000). The ordered weighted geometric operator: properties and application in MCDM Problems. In Proceedings of the 8th Conference on Information Processing and Management of Uncertainty in Knowledge-Based Systems (IPMU), Citeseer.
- Chou, J.-S., Pham, A.-D., & Wang, H. (2013). Bidding strategy to support decision-making by integrating fuzzy AHP and regression-based simulation. *Automation in Construction* 35, 517–527.
- da Costa Sousa, J. M., & Kaymak, U. (2001). Model predictive control using fuzzy decision functions. *IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics*, 31(1), 54–65.
- Dejus, T., & Antucheviciene, J. (2013). Assessment of health and safety solutions at a construction site. *Journal of Civil Engineering and management*, 19(5), 728–737.
- Deng, J. (1982). Grey system fundamental method. Huazhong University of Science and Technology Wuhan, China.
- Deng, J. (1988). *Grey system*. Beijing: China Ocean Press.
- Dubois, D., & Prade, H. (1980). Systems of linear fuzzy constraints. *Fuzzy Sets and Systems*, 3(1), 37–48.
- Ertay, T., Kahraman, C., & Kaya, İ. (2013). Evaluation of renewable energy alternatives using MACBETH and fuzzy AHP multicriteria methods: the case of Turkey. *Technological and Economic Development of Economy*, 19(1), 38–62.
- Fodor, J. C., & Roubens, M. (1995). Characterization of weighted maximum and some related operations. *Information Sciences*, 84(3), 173–180.
- Fontela, E., & Gabus, A. (1976). The DEMATEL observer, DEMATEL.
- Gadakh, V., Shinde, V., & Khemnar, N. (2013). Optimization of welding process parameters using MOORA method. *The International Journal of Advanced Manufacturing Technology*, 69(9–12), 2031–2039.
- Gal, T., Stewart, T., & Hanne, T. (1999). *Multicriteria decision making: Advances in MCDM models, algorithms, theory, and applications*. Cambridge, MA: Da Capo Press.
- Gudiene, N., Banaitis, A., Podvezko, V., & Banaitiene, N. (2014). Identification and evaluation of the critical success factors for construction projects in Lithuania: AHP approach. *Journal of Civil Engineering and Management*, 20(3), 350–359.
- Hashemkhani Zolfani, S., Farrokhzad, M., & Turskis, Z. (2013b). Investigating on successful factors of online games based on explorer. *E & M: Ekonomie a Management*, 16(2), 161–169.
- Hashemkhani Zolfani, S., & Saporas, J. (2013). New application of SWARA method in prioritizing sustainability assessment indicators of energy system. *Inzinerine Ekonomika-Engineering Economics*, 24(5), 408–414.
- Hashemkhani Zolfani, S., Aghdaie, M. H., Derakhti, A., Zavadskas, E. K., & Morshed Varzandeh, M. H. (2013b). Decision making on business issues with foresight perspective; an application of new hybrid MCDM model in shopping mall locating. *Expert Systems with Applications*, 40(17), 7111–7121.
- 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.
- Hatami-Marbini, A., Tavana, M., Moradi, M., & Kangi, F. (2013). A fuzzy group Electre method for safety and health assessment in hazardous waste recycling facilities. *Safety Science*, 51(1), 414–426.
- Hong, D. H., & Choi, C.-H. (2000). Multicriteria fuzzy decision-making problems based on vague set theory. *Fuzzy Sets and Systems*, 114(1), 103–113.

- Hsu, L.-C. (2015). Using a decision-making process to evaluate efficiency and operating performance for listed semiconductor companies. *Technological and Economic Development of Economy*, 21(2), 301–331.
- Hwang, C.-L., & Lin, M.-J. (1987). *Group decision making under multiple criteria*. Berlin: Springer.
- Hwang, C.-L., Masud, A. S. M., Paidy, S. R., & Yoon, K. P. (1979). *Multiple objective decision making, methods and applications: A state-of-the-art survey*. Berlin: Springer.
- Hwang, C., & Yoon, K. (1981). *Multiple attribute decision making: Methods and applications, A State of the Art Survey*. New York: Springer.
- Hwang, F. P., Chen, S. J., & Hwang, C. L. (1992). *Fuzzy multiple attribute decision making: Methods and applications*. Berlin: Springer.
- Inuiguchi, M., Ichihashi, H., & Tanaka, H. (1990). Fuzzy programming: A survey of recent developments. In *Stochastic versus fuzzy approaches to multiobjective mathematical programming under uncertainty* (pp. 45–68). Dordrecht: Springer.
- Jana, T. K., Bairagi, B., Paul, S., Sarkar, B., & Saha, J. (2013). Dynamic schedule execution in an agent based holonic manufacturing system. *Journal of Manufacturing Systems*, 32(4), 801–816.
- Jaskowski, P., Biruk, S., & Bucon, R. (2010). Assessing contractor selection criteria weights with fuzzy AHP method application in group decision environment. *Automation in Construction*, 19(2), 120–126.
- Jato-Espino, D., Castillo-Lopez, E., Rodriguez-Hernandez, J., & Canteras-Jordana, J. C. (2014). A review of application of multi-criteria decision-making methods in construction. *Automation in Construction*, 45, 151–162.
- Kahraman, C., & Çebi, S. (2009). A new multi-attribute decision making method: Hierarchical fuzzy axiomatic design. *Expert Systems with Applications*, 36(3, Part 1), 4848–4861.
- Kahraman, C., & Kaya, İ. (2012). A fuzzy multiple attribute utility model for intelligent building assessment. *Journal of Civil Engineering and Management*, 18(6), 811–820.
- Kaklauskas, A., Tupenaite, L., Kanapeckiene, L., & Naimaviciene, J. (2013). Knowledge-based model for standard housing renovation. *Procedia Engineering*, 57, 497–503.
- Kaklauskas, A., Zavadskas, E. K., Naimaviciene, J., Krutinis, M., Plakys, V., & Venskus, D. (2010). Model for a complex analysis of intelligent built environment. *Automation in Construction*, 19(3), 326–340.
- Kaklauskas, A., Zavadskas, E. K., Raslanas, S., Ginevicius, 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.
- Kaklauskas, A., Zavadskas, E. K., & Trinkunas, V. (2007b). A multiple criteria decision support on-line system for construction. *Engineering Applications of Artificial Intelligence*, 20(2), 163–175.
- Kalibatas, D., & Turskis, Z. (2008). Multicriteria evaluation of inner climate by using MOORA method. *Information Technology and Control*, 37(1), 79–83.
- Kalibatas, D., Zavadskas, E. K., & Kalibatiene, D. (2012). A method of multi-attribute assessment using ideal alternative: Choosing an apartment with optimal indoor environment. *International Journal of Strategic Property Management*, 16(3), 338–353.
- Kanapeckiene, L., Kaklauskas, A., Zavadskas, E. K., & Seniut, M. (2010). Integrated knowledge management model and system for construction projects. *Engineering Applications of Artificial Intelligence*, 23(7), 1200–1215.
- Kaya, İ., & Kahraman, C. (2014). A comparison of fuzzy multicriteria decision making methods for intelligent building assessment. *Journal of Civil Engineering and Management*, 20(1), 59–69.
- Keeney, R. L., Raiffa, H., & Rajala, D. W. (1979). Decisions with multiple objectives: Preferences and value trade-offs. *IEEE Transactions on Systems, Man and Cybernetics*, 9(7), 403–403.

- Kersuliene, V., & Turskis, Z. (2011). Integrated fuzzy multiple criteria decision-making model for architect selection. *Technological and Economic Development of Economy*, 17(4), 645–666.
- Kersuliene, V., Zavadskas, E. K., & Turskis, Z. (2010). Selection of rational dispute resolution method by applying new step-wise weight assessment ratio analysis (SWARA). *Journal of Business Economics and Management*, 11(2), 243–258.
- Kildiene, S. (2013). Assessment of opportunities for construction enterprises in European Union member states using the MULTIMOORA method. *Procedia Engineering* 57, 557–564.
- Koksalan, M. M., & Wallenius, J., & Zionts, S. (2011). *Multiple criteria decision making: from early history to the 21st century*. Singapore: World Scientific.
- Kracka, M., Zavadskas, E. K. (2013). Panel building refurbishment elements effective selection by applying multiple-criteria methods. *International Journal of Strategic Property Management*, 17(2), 210–219.
- Krylovas, A., Zavadskas, E. K., Kosareva, N., & Dadelo, S. (2014). New KEMIRA method for determining criteria priority and weights in solving MCDM problem. *International Journal of Information Technology & Decision Making*, 13(6), 1119–1133.
- Kucukvar, M., Gumus, S., Egilmez, G., & Tatari, O. (2014). Ranking the sustainability performance of pavements: An intuitionistic fuzzy decision-making method. *Automation in Construction*, 40, 33–43.
- Lapinskiene, V., & Martinaitis, V. (2013). The framework of an optimization model for building envelope. *Procedia Engineering* 57, 670–677.
- Li, D.-F. (2005). Multiattribute decision making models and methods using intuitionistic fuzzy sets. *Journal of Computer and System Sciences*, 70(1), 73–85.
- Lin, L.-K., Chang, C.-C., & Lin, Y.-C. (2011). Structure development and performance evaluation of construction knowledge management system. *Journal of Civil Engineering and Management*, 17(2), 184–196.
- Liu, H.-W., & Wang, G.-J. (2007). Multi-criteria decision-making methods based on intuitionistic fuzzy sets. *European Journal of Operational Research*, 179(1), 220–233.
- MacCrimmon, K. R. (1968). Decision making among multiple-attribute alternatives: A survey and consolidated approach, DTIC Document.
- Maity, S. R., Chatterjee, P., & Chakraborty, S. (2012). Cutting tool material selection using grey complex proportional assessment method. *Materials & Design*, 36, 372–378.
- Marcic, D., Ceric, A., & Kovacevic, M. S. (2013). Selection of a field testing method for karst rock mass deformability by multi criteria decision analysis. *Journal of Civil Engineering and Management*, 19(2), 196–205.
- Mardani, A., Jusoh, A., Md Nor, K., Khalifah, Z., Zakwan, N., & Valipour, A. (2015a). Multiple criteria decision-making techniques and their applications – a review of the literature from 2000 to 2014. *Economic Research-Ekonomska Istraživanja*, 28(1), 516–571.
- Mardani, A., Jusoh, A., & Zavadskas, E. K. (2015b). Fuzzy multiple criteria decision-making techniques and applications—Two decades review from 1994 to 2014. *Expert Systems with Applications*, 42(8), 4126–4148.
- Mareschal, B., Brans, J. P., & Vincke, P. (1984). PROMETHEE: A new family of outranking methods in multicriteria analysis, ULB–Université Libre de Bruxelles.
- Medineckiene, M., & Bjork, F. (2011). Owner preferences regarding renovation measures—the demonstration of using multi-criteria decision making. *Journal of Civil Engineering and Management*, 17(2), 284–295.
- Miettinen, K. (1999). *Nonlinear multiobjective optimization*. Berlin: Springer.
- Miyamoto, S., Liu, Z.-Q., & Kunii, T. (2000). *Soft computing and human-centered machines*. New York: Springer.
- Mohammadi, F., Sadi, M. K., Nateghi, F., Abdullah, A., & Skitmore, M. (2014). A hybrid quality function deployment and cybernetic analytic network process model for project manager selection. *Journal of Civil Engineering and Management*, 20(6), 795–809.
- Moravej, Z., & Afshar, H. (2014). Optimal Planning of microgrid using multi criteria decision analysis. *International Journal of Multidisciplinary Sciences and Engineering*, 5(8), 1–6.

- Mulliner, E., Smallbone, K., & Maliene, V. (2013). An assessment of sustainable housing affordability using a multiple criteria decision-making method. *Omega*, 41(2), 270–279.
- Nazarko, J., & Chodakowska, E. (2015). Measuring productivity of construction industry in Europe with Data Envelopment Analysis. *Procedia Engineering*, 122, 204–212.
- Nguyen, H.-T., Dawal, S. Z. M., Nukman, Y., & Aoyama, H. (2014). A hybrid approach for fuzzy multi-attribute decision making in machine tool selection with consideration of the interactions of attributes. *Expert Systems with Applications*, 41(6), 3078–3090.
- Nieto-Morote, A., & Ruz-Vila, F. (2012). A fuzzy multi-criteria decision-making model for construction contractor prequalification. *Automation in Construction*, 25, 8–19.
- Nuuter, T., Lill, I., & Tupenaite, L. (2015). Comparison of housing market sustainability in European countries based on multiple criteria assessment. *Land Use Policy*, 42, 642–651.
- Opricovic, S. (1998). Multicriteria optimization of civil engineering systems. *Faculty of Civil Engineering, Belgrade*, 2(1), 5–21.
- Opricovic, S., & Tzeng, G. H. (2002). Multicriteria planning of post-earthquake sustainable reconstruction. *Computer-Aided Civil and Infrastructure Engineering*, 17(3), 211–220.
- Peneva, V., & Popchev, I. (2008). Multicriteria decision making based on fuzzy relations. *Cybernetics and Information Technologies*, 8(4), 3–12.
- Pinter, U., Psunder, I. (2013). Evaluating construction project success with use of the M-TOPSIS method. *Journal of Civil Engineering and Management*, 19(1), 16–23.
- Podvezko, V. (2011). The comparative analysis of MCDA methods SAW and COPRAS. *Engineering Economics*, 22(2), 134–146.
- Popovic, G., Stanujkic, D., & Stojanovic, S. (2012). Investment project selection by applying copras method and imprecise data. *Serbian Journal of Management*, 7(2), 257–269.
- Rabbani, A., Zamani, M., Yazdani-Chamzini, A., & Zavadskas, E. K. (2014). Proposing a new integrated model based on sustainability balanced scorecard (SBSC) and MCDM approaches by using linguistic variables for the performance evaluation of oil producing companies. *Expert Systems with Applications*, 41(16), 7316–7327.
- Radziszewski, P., Nazarko, J., Vilutiene, T., & et al. (2016). Future trends in road pavement technologies development in the context of environmental protection. *Baltic Journal Of Road And Bridge Engineering*, 11(2), 160–168.
- Razavi Hajiagha, S. H., Hashemi, S. S., & Zavadskas, E. K. (2013). A complex proportional assessment method for group decision making in an interval-valued intuitionistic fuzzy environment. *Technological and Economic Development of Economy*, 19(1), 22–37.
- Roy, B. (1968). Classement et choix en présence de points de vue multiples. *RAIRO-Operations Research-Recherche Opérationnelle* 2 (V1), 57–75.
- Roy, B. (1971). Problems and methods with multiple objective functions. *Mathematical Programming*, 1(1), 239–266.
- Roy, B. (1978). ELECTRE III: Un algorithme de classements fondé sur une représentation floue des préférences en présence de critères multiples. *Cahiers du CERO*, 20(1), 3–24.
- Roy, B. (1996). *Multicriteria methodology for decision aiding*. Boston: Springer.
- Roy, B., & Bertier, P. (1973). La Méthode ELECTRE II (Une application au média-planning...).
- Ruzgys, A., Volvaciovas, R., Ignatavicius, C., & Turskis, Z. (2014). Integrated evaluation of external wall insulation in residential buildings using SWARA-TODIM MCDM method. *Journal of Civil Engineering and Management*, 20(1), 103–110.
- Saaty, T. L. (1971). On polynomials and crossing numbers of complete graphs. *Journal of Combinatorial Theory, Series A* 10(2), 183–184.
- Saaty, T. L. (1980). *The analytic hierarchy process: Planning, priority setting, resources allocation*. New York: McGraw.
- Saaty, T. L. (1988). *What is the analytic hierarchy process?* Cham: Springer.
- Saaty, T. L. (1996). *Decision making with dependence and feedback: The analytic network process*. Pittsburgh: University of Pittsburgh.
- Safa, M., Shahi, A., Haas, C. T., & Hipel, K. W. (2014). Supplier selection process in an integrated construction materials management model. *Automation in Construction*, 48, 64–73.



- Sahu, A. K., Sahu, N. K., & Sahu, A. K. (2014). Appraisal of CNC machine tool by integrated MULTI-MOORA-IVGN circumferences: An empirical study. *Grey Systems: Theory and Application*, 4(1), 104–123.
- Simanaviciene, R., Liaudanskiene, R., & Ustinovichius, L. (2012). A new synthesis method of structural, technological and safety decisions (SyMAD-3). *Journal of Civil Engineering and Management*, 18(2), 265–276.
- Siozinyte, E., & Antucheviciene, J. (2013). Solving the problems of daylighting and tradition continuity in a reconstructed vernacular building. *Journal of Civil Engineering and Management*, 19(6), 873–882.
- Skibniewski, M. J., & Chao, L.-C. (1992). Evaluation of advanced construction technology with AHP method. *Journal of Construction Engineering and Management*, 118(3), 577–593.
- Sliogeriene, J., Turskis, Z., & Streimikiene, D. (2013). Analysis and choice of energy generation technologies: The multiple criteria assessment on the case study of Lithuania. *Energy Procedia* 32, 11–20.
- Śłowiński, R. (1986). A multicriteria fuzzy linear programming method for water supply system development planning. *Fuzzy Sets and Systems*, 19(3), 217–237.
- Staniunas, M., Medineckiene, M., Zavadskas, E. K., & Kalibatas, D. (2013). To modernize or not: Ecological–economical assessment of multi-dwelling houses modernization. *Archives of Civil and Mechanical Engineering*, 13(1), 88–98.
- Stankeviciene, J., & Sviderske, T. (2012). Country risk assessment based on MULTIMOORA. In *The 7th international scientific conference Business and Management* (pp. 530–536).
- Stanujkic, D., Magdalinovic, N., Milanovic, D., Magdalinovic, S., & Popovic, G. (2014). An efficient and simple multiple criteria model for a grinding circuit selection based on MOORA method. *Informatica*, 25(1), 73–93.
- Streimikiene, D., Balezentis, T., Krisciukaitiene, I., & Balezentis, A. (2012). Prioritizing sustainable electricity production technologies: MCDM approach. *Renewable and Sustainable Energy Reviews*, 16(5), 3302–3311.
- Tamosaitiene, J., & Gaudutis, E. (2013). Complex assessment of structural systems used for high-rise buildings. *Journal of Civil Engineering and Management*, 19(2), 305–317.
- Tarlochan, F., Samer, F., Hamouda, A. M. S., Ramesh, S., & Khalid, K. (2013). Design of thin wall structures for energy absorption applications: Enhancement of crashworthiness due to axial and oblique impact forces. *Thin-Walled Structures*, 71, 7–17.
- Torra, V. (2010). Hesitant fuzzy sets. *International Journal of Intelligent Systems*, 25(6), 529–539.
- Torra, V., & Narukawa, Y. (2009). On hesitant fuzzy sets and decision. In *2009 IEEE International Conference on Fuzzy Systems* (pp. 1378–1382).
- Turskis, Z. (2008). Multi-attribute contractors ranking method by applying ordering of feasible alternatives of solutions in terms of preferability technique. *Technological and Economic Development of Economy*, 14(2), 224–239.
- Turskis, Z., Zavadskas, E. K., Antucheviciene, J., & Kosareva, N. (2015). A hybrid model based on fuzzy AHP and fuzzy WASPAS for construction site selection. *International Journal of Computers Communications & Control*, 10(6), 113–128.
- Turskis, Z., & Zavadskas, E. K. (2010a). A new fuzzy additive ratio assessment method (ARAS-F). Case study: The analysis of fuzzy multiple criteria in order to select the logistic centers location. *Transport*, 25(4), 423–432.
- Turskis, Z., & Zavadskas, E. K. (2010b). A novel method for multiple criteria analysis: Grey additive ratio assessment (ARAS-G) method. *Informatica*, 21(4), 597–610.
- Turskis, Z., Zavadskas, E. K., & Kutut, V. (2013). A model based on ARAS-G and AHP methods for multiple criteria prioritizing of heritage value. *International Journal of Information Technology & Decision Making*, 12(1), 45–73.
- Tzeng, G.-H., & Huang, J.-J. (2011). *Multiple attribute decision making: Methods and applications*. Boca Raton: CRC Press.
- Ulubeyli, S., & Kazaz, A. (2009). A multiple criteria decision-making approach to the selection of concrete pumps. *Journal of Civil Engineering and Management*, 15(4), 369–376.

- Uzsilaityte, L., & Martinaitis, V. (2010). Search for optimal solution of public building renovation in terms of life cycle. *Journal of Environmental Engineering and Landscape Management*, 18(2), 102–110.
- Vafaeipour, M., Hashemkhani Zolfani, S., Morshed Varzandeh, M. H., Derakhti, A., & Keshavarz Eshkalag, M. (2014). Assessment of regions priority for implementation of solar projects in Iran: New application of a hybrid multi-criteria decision-making approach. *Energy Conversion and Management*, 86, 653–663.
- Vahdani, B., Mousavi, S. M., Tavakkoli-Moghaddam, R., Ghodrathnama, A., & Mohammadi, M. (2014). Robot selection by a multiple criteria complex proportional assessment method under an interval-valued fuzzy environment. *The International Journal of Advanced Manufacturing Technology*, 72(5–8), 687–697.
- Wang, W.-C., Yu, W.-D., Yang, I.-T., Lin, C.-C., Lee, M.-T., & Cheng, Y.-Y. (2013). Applying the AHP to support the best-value contractor selection—lessons learned from two case studies in Taiwan. *Journal of Civil Engineering and Management*, 19(1), 24–36.
- Xu, Z. (2004a). EOWA and EOWG operators for aggregating linguistic labels based on linguistic preference relations, *International Journal of Uncertainty, Fuzziness and Knowledge-based Systems*, 12(6), 791–810.
- Xu, Z. (2004b). A method based on linguistic aggregation operators for group decision making with linguistic preference relations. *Information Sciences*, 166(1), 19–30.
- Xu, Z., & Da, Q. (2002). The ordered weighted geometric averaging operators. *International Journal of Intelligent Systems*, 17(7), 709–716.
- Yager, R. R. (1986). A characterization of the extension principle. *Fuzzy Sets and Systems*, 18(3), 205–217.
- Yager, R. R. (1988). On ordered weighted averaging aggregation operators in multicriteria decisionmaking. *IEEE Transactions on Systems, Man and Cybernetics*, 18(1), 183–190.
- Yager, R. R. (1994). On weighted median aggregation. *International Journal of Uncertainty, Fuzziness and Knowledge-based Systems*, 2(1), 101–113.
- Yager, R. R. (2004). OWA aggregation over a continuous interval argument with applications to decision making. *IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics*, 34(5), 1952–1963.
- Yu, D., Wu, Y., Zhou, W. (2012). Generalized hesitant fuzzy Bonferroni mean and its application in multi-criteria group decision making. *Journal of Information and Computational Science*, 9(2), 267–274.
- Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, 8(3), 338–353.
- Zavadskas, E. K., & Antucheviciene, J. (2007). Multiple criteria evaluation of rural building's regeneration alternatives. *Building and Environment*, 42(1), 436–451.
- Zavadskas, E. K., Antucheviciene, J., Hajiagha, S. H. R., Hashemi, S. S. (2014a). Extension of weighted aggregated sum product assessment with interval-valued intuitionistic fuzzy numbers (WASPAS-IVIF). *Applied Soft Computing*, 24, 1013–1021.
- Zavadskas, E. K., Antucheviciene, J., Hajiagha, S. H. R., & Hashemi, S. S. (2015c). The interval-valued intuitionistic fuzzy MULTIMOORA method for group decision making in engineering. *Mathematical Problems in Engineering*, Article Number 560690.
- Zavadskas, E. K., Antucheviciene, J., Sapauskas, J., & Turskis, Z. (2013a). MCDM methods WASPAS and MULTIMOORA: Verification of robustness of methods when assessing alternative solutions. *Economic Computation and Economic Cybernetics Studies and Research*, 47(2), 5–20.
- Zavadskas, E. K., Kaklauskas, A., & Sarka, V. (1994). The new method of multicriteria complex proportional assessment of projects. *Technological and Economic Development of Economy*, 1(3), 131–139.
- Zavadskas, E. K., Kaklauskas, A., Banaitis, A., & Kvederyte, N. (2004). Housing credit access model: The case for Lithuania. *European Journal of Operational Research*, 155(2), 335–352.
- Zavadskas, E. K., Kaklauskas, A., Turskis, Z., & Tamosaitiene, J. (2008c). Selection of the effective dwelling house walls by applying attributes values determined at intervals. *Journal of Civil Engineering and Management*, 14(2), 85–93.

- Zavadskas, E. K., Kaklauskas, A., Turskis, Z., & Tamosaitiene, J. (2009b). Multi-attribute decision-making model by applying grey numbers. *Informatica*, 20(2), 305–320.
- Zavadskas, E. K., Skibniewski, M. J., & Antucheviciene, J. (2014b). Performance analysis of civil engineering journals based on the Web of Science® database. *Archives of Civil and Mechanical Engineering*, 14(4), 519–527.
- Zavadskas, E. K., & Turskis, Z. (2010). A new additive ratio assessment (ARAS) method in multicriteria decision-making. *Technological and Economic Development of Economy*, 16(2), 159–172.
- Zavadskas, E. K., Turskis, Z., & Antucheviciene, J. (2015b). Selecting a contractor by using a novel method for multiple attribute analysis: Weighted aggregated sum product assessment with grey values (WASPAS-G). *Studies in Informatics and Control*, 24(2), 141–150.
- Zavadskas, E. K., Turskis, Z., & Bagocius, V. (2015a). Multi-criteria selection of a deep-water port in the Eastern Baltic Sea. *Applied Soft Computing*, 26, 180–192.
- Zavadskas, E. K., Turskis, Z., & Kildiene, S. (2014c). State of art surveys of overviews on MCDM/MADM methods. *Technological and Economic Development of Economy*, 20(1), 165–179.
- Zavadskas, E. K., Turskis, Z., & Tamosaitiene, J. (2010b). Risk assessment of construction projects. *Journal of Civil Engineering and Management*, 16(1), 33–46.
- Zavadskas, E. K., Turskis, Z., & Vilutiene, T. (2010a). Multiple criteria analysis of foundation instalment alternatives by applying Additive Ratio Assessment (ARAS) method. *Archives of Civil and Mechanical Engineering*, 10(3), 123–141.
- Zavadskas, E. K., Turskis, Z., Antucheviciene, J., & Zakarevicius, A. (2012a). Optimization of weighted aggregated sum product assessment. *Elektronika ir Elektrotechnika*, 122(6), 3–6.
- Zeleny, M., & Cochrane, J. L. (1982). *Multiple criteria decision making*. New York: McGraw-Hill.
- Zhu, B., Xu, Z., & Xia, M. (2012). Hesitant fuzzy geometric Bonferroni means. *Information Sciences*, 205, 72–85.