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REVIEW ARTICLE

Multiple criteria decision-making techniques and their applications – a review of the literature from 2000 to 2014

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Multiple criteria decision-making (MCDM) is considered as a complex decision-making (DM) tool involving both quantitative and qualitative factors. In recent years, several MCDM techniques and approaches have been suggested to choosing the optimal probable options. The purpose of this article is to systematically review the applications and methodologies of the MCDM techniques and approaches. This study reviewed a total of 393 articles published from 2000 to 2014 in more than 120 peer reviewed journals (extracted from Web of Science). According to experts' opinion, these articles were grouped into 15 fields. Furthermore, these articles were categorised based on authors, publication date, name of journals, methods, tools, and type of research (MCDM utilising research, MCDM developing research, and MCDM proposing research). The results of this study indicated that in 2013 scholars have published articles more than in other years. In addition, the analytic hierarchy process (AHP) method in the individual tools and hybrid MCDM in the integrated methods were ranked as the first and second methods in use. Additionally, the *European Journal of Operational Research* as the first journal with 70 publications was the significant journal in this study. Finally, energy, environment and sustainability were ranked as the first areas that have applied MCDM techniques and approaches.

Keywords: decision-making techniques and approaches; multiple criteria decision-making (MCDM); literature review

JEL classification: C4-C44

1. Introduction

Multiple criteria decision-making (MCDM) has grown as a part of operations research, concerned with designing computational and mathematical tools for supporting the subjective evaluation of performance criteria by decision-makers (Zavadskas, Turskis, & Kildienė, 2014). Several studies have been carried out to develop MCDM (Zavadskas & Turskis, 2010; Zavadskas, Turskis, Antucheviciene, & Zakarevicius, 2012). In recent years several previous studies have employed MCDM tools and applications to solve area problems such as energy, environment and sustainability (Şengül, Eren, Eslamian Shiraz, Gezder, & Şengül, 2015; Soltani, Hewage, Reza, & Sadiq, 2015; Zavadskas, Turskis, & Bagočius, 2015), supply chain management (Rajesh & Ravi, 2015), material (Zavadskas, Kaklauskas, Trinkunas, & Trinkuniene, 2004), quality management (Lupo,

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2015), GIS (Latinopoulos & Kechagia, 2015), construction and project management (Monghasemi, Nikoo, Khaksar Fasaee, & Adamowski, 2015), safety and risk management (Ilangkumaran, Karthikeyan, Ramachandran, Boopathiraja, & Kirubakaran, 2015), manufacturing systems, technology and information management (Oztaysi, 2014), operation research and soft computing (Angilella & Mazzù, 2015; Bouyssou & Marchant, 2015; Zhu, Xu, Zhang, & Hong, 2015; Del Vasto-Terrientes, Valls, Słowiński, & Zielniewicz, 2015; Chen, 2015; Roszkowska & Wachowicz, 2015), strategic management (Hosseini Nasab & Milani, 2012), production management (Rabbani, Zamani, Yazdani-Chamzini, & Zavadskas, 2014) and tourism management (Akincilar & Dagdeviren, 2014).

Since the 1960s, MCDM has been an active research area and produced many theoretical and applied articles and books (Roy, 2005). MCDM methods have been designed to designate a preferred alternative, classify alternatives in a small number of categories, and/or rank alternatives in a subjective preference order. MCDM is a generic term for all methods that exist for helping people make decisions according to their preferences, in cases where there is more than one conflicting criterion (Ho, 2008). Using MCDM can be said to be a way of dealing with complex problems by breaking the problems into smaller pieces. After weighing some considerations and making judgements about smaller components, the pieces are reassembled to present an overall picture to the DMs. Most of MCDM methods deal with discrete alternatives, which are described by a set of criteria. Criteria values can be determined as a cardinal or ordinal information. Information could be determined exactly or could be fuzzy, determined in intervals. Modern MCDM methods enable decision-makers to deal with all above mentioned types of information. One of the problems encountered during the MCDM process is the choice of the aggregation procedure for solving the decision problem. However, multiple criteria decision analysts provide a variety of aggregation procedures. Recent decades have seen a dramatic increase on all main areas of MCDM: Formal models (algorithms, procedures and selection paradigms); Evaluation theories (assumptions about values or preferences and structured representations of values or preferences); Assessment methodologies (elicitation, estimation and scaling of individuals' preferences, utilities and subjective probabilities in MCDM situations) (Fishburn, 1978; Zavadskas et al., 2014). There is no unique and well-defined methodology that one could follow step-by-step from the beginning to the end of a decision aiding process. When dealing with objects that can only be described and compared using several characteristics, aggregation is a major issue: it aims at operating a synthesis of the, usually contradictory, features of the objects, in view of achieving a goal such as choosing among the objects, rank ordering them, sorting them into categories and so on (Bouyssou, Marchant, Pirlot, Tsoukias, & Vincke, 2006).

This study has the following contributions: MCDM is one of the most widely used decision methodologies in various fields such as; energy and environment, business, economy, production, and so on. MCDM techniques and approaches improve the quality of decisions by creating the development more efficient, rational and explicit. Several studies (Behzadian, Kazemzadeh, Albadvi, & Aghdasi, 2010; Ho, 2008; Vaidya & Kumar, 2006) have demonstrated the vitality of the field and reported several methods proposed in the literature. A large number of approaches and techniques have been introduced in this area of study. However, previously-conducted surveys have not kept pace. Thus, we believe that there is a need for a new systematic survey to consolidate recent research conducted on this area of study. In recent decades, the MCDM techniques and approaches have received a great deal of attention from practitioners and

researchers. This article attempts to document the exponentially grown interest in the MCDM techniques and approaches and provide a state-of the-art review of the literature regarding the MCDM applications and methodologies. Based on a classification scheme, a reference repository has been established, including 393 articles published in more than 120 international journals from 2000. Articles are classified based on the year of publication, application areas, authors' nationality, and MCDM techniques and approaches combined with other methods. This article is evolving a categorising structure with a focus on applicable considerations, presenting an organised review in a way to provide a guide to previous studies on the MCDM tools and approaches, and recognising topics for future research. Additionally, in our study, two new perspectives are taken into consideration to review the articles, namely categorisation of the articles into 15 fields (energy, environment and sustainability, supply chain management, material, quality management, GIS, construction and project management, safety and risk management, manufacturing systems, technology management, operation research and soft computing, strategic management, knowledge management, production management, tourism management and other fields) and examination of the type of study (MCDM utilising research, MCDM developing research, MCDM proposing research).

In this article, the literature related to the descriptors of MCDM has been reviewed comprehensively using academic databases of Web of Science. Following a methodological decision analysis on the whole collected articles, a total of 393 international journal articles published from 2000 to 2014 were reviewed. This article attempts to answer the following questions: (1) which decision-making (DM) techniques have been used?; (2) Which type of study has been conducted on these MCDM techniques?; (3) Which one of the 15 fields (Energy, environment and sustainability, Supply chain management, Material, Quality management, GIS, construction and project management, safety and risk management, manufacturing systems, technology management, operation research and soft computing, strategic management, knowledge management, production management, tourism management and other fields) has further used these MCDM techniques and approaches?; (4) What kinds of MCDM techniques and approaches have been employed in these years based on 15 fields?; (5) Which journal published articles related to these MCDM techniques and approaches?; and (6) In which year, the previous authors published more papers regarding MCDM techniques and approaches based on the 15 fields?

The remainder of this article is organised as follows. Section 2 provides a brief overview of the literature review and framework. Section 3 describes the research methodology and the procedure of this study. Section 4 provides the findings of this review based on the research objectives and questions. Section 5 discusses the results based on the research questions. Finally, Section 6 presents the conclusion, limitations and recommendations for future studies.

2. Summary of the literature review

MCDM methods cover a wide range of quite distinct approaches. MCDM methods can be broadly classified into two categories: discrete MCDM or discrete Multi-attribute Decision-Making (MADM) and continuous Multi-objective Decision-Making (MODM) methods (Chauhan & Vaish, 2012; Zavadskas et al., 2014). Recently, hundreds of publications have been published to provide information about MCDM methods, their development and application in different fields. This article attempts to document the exponentially grown interest in the MCDM techniques and approaches and provide a

state-of the-art review of the literature regarding the MCDM applications and methodologies. The research is based on Web of Science database, which is a part of Thomson Reuters Web of Knowledge. The 1970s was an important decade for many seminal works. The foundations of modern MCDM were developed in 1950s and 1960s. The development of MCDM research accelerated during the 1980s and early 1990s, and seems to have continued its exponential growth (Köksalan, Wallenius, & Zionts, 2011). The book by Köksalan, Wallenius, and Zionts (2011) provides a brief history of the development of MCDM methods. It briefly describes the development of the area from ancient to modern times. Keeney, Raiffa, and Rajala (1979), formulated the basics of Decision with Multiple Objectives. Hwang and Masud (1979), provided review on development of MODM methods and applications in a relatively short period of time. Later, Tzeng and Huang (Tzeng & 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 on the analytic hierarchy process (AHP). Later, Saaty (1996) published a study on the further development of the analytic network process (ANP) method. Zeleny and Cochrane (1982) published a book which deals with the problem of compromise theory. Hwang and Lin (1967), published a study for Group Decision Making Under Multi-criteria. Roy (1996) summarised the information on ELECTRE group methods. Seminal studies have been prepared by Belton and Stewart (2002) and Gal, Stewart, and Hanne (1999), Miettinen (1999). Brauers (2004) published a study on the basis of which multi-objective. optimization by ratio analysis (MOORA), and multiple objective optimization on the basis of ratio analysis plus full multiplicative form (MULTIMOORA) methods were developed. Recently, the development of hybrid and modular methods is becoming increasingly important. They are based on previously developed well-known methods, such as TOPSIS (Hwang & Yoon, 1981), SAW (MacCrimmon & Rand, 1968), AHP (Saaty, 1971, 1988), ANP (Saaty, 1996), Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR; Opricovic, 1998; Opricovic & Tzeng, 2002), decision making trial and evaluation laboratory (DEMATEL; Fontela & Gabus, 1976), DEA (Charnes, 1994; Charnes, Cooper, & Rhodes, 1978), preference ranking organization method for enrichment evaluations (PROMETHEE; Mareschal, Brans, & Vincke, 1984), ELECTRE (Roy, 1968, 1971, 1978; Roy & Bertier, 1972) and their modification, by applying fuzzy and grey number theory. Relatively recently developed MCDM methods, such as generalized regression with intensities of preference (GRIP; Figueira, Greco, & Słowiński, 2009), complex proportional assessment method (COPRAS; Zavadskas & Antucheviciene, 2007; Zavadskas, Kaklauskas, & Sarka, 1994; Zavadskas, Kaklauskas, Turskis, & Tamošaitiene, 2008), additive ratio assessment (ARAS; Turskis & Zavadskas, 2010; Zavadskas & Turskis, 2010; Zavadskas et al., 2008), RUTA (Kadziński, Greco, & Słowiński, 2013) MOORA (Brauers & Zavadskas, 2006), UTADIS^{GMS} (Greco, Kadziński, & Słowiński, 2011), MULTIMOORA (Brauers & Zavadskas, 2010), step-wise weight assessment ratio analysis (SWARA; Keršuliene, Zavadskas, & Turskis, 2010) and weighted aggregated sum product assessment (WASPAS; Zavadskas, Turskis, Antucheviciene, & Zakarevicius, 2012) are rapidly developed and applied to solve real life problems.

3. Research methodology

This article reviews the literature in order to recognise the articles that have been published in popular journals and provided the most important information to practitioners and researchers who investigate issues related to the MCDM methods. To this end, an extensive search was carried out to find MCDM in titles, abstracts, keywords, and research methodologies of the article. This article attempts to document the exponentially grown interest in the MCDM methods and provide a state-of the-art review of the literature regarding the MCDM applications and methodologies. According to a classification scheme, a reference repository, including a total of 393 published articles in more than 120 journals since 2000, has been established. The articles are classified in terms of the application areas, publication year, the journal's name and MCDM techniques and approaches. The present article has three contributions: the development of a classification scheme with a focus on practical considerations, structurally reviewing the literature to guide the research on the MCDM techniques and approaches, and the identification of issues to be studied in future. Additionally, two new perspectives are taken into consideration to review the articles, namely the categorisation of the articles into four 15 fields (energy, environmental and sustainability, supply chain management, material, quality management, GIS, construction and project management, safety and risk management, manufacturing systems, technology management, operation research and soft computing, strategic management, knowledge management, production management, tourism management and other fields) and examination of the type of study (MCDM utilising research, MCDM developing research, MCDM proposing research).

In particular, we targeted Web of Science which covers the most important journals in 15 fields. Items such as doctoral dissertations, master's theses, textbooks, conference proceeding articles, and unpublished articles were ignored in this review. For this review, the primary data were collected from 393 cited articles related to MCDM published since 2000. For choose 393 scholarly journal articles we have used most of international journals specially related to DM methods. Some of journals cited in this review were, *Expert Systems with Applications, Applied Soft Computing, Journal of Intelligent and Fuzzy Systems, Information Sciences, International Journal of Production Research, Technological and Economic Development of Economy, European Journal of Operational Research, International Journal of Intelligent Systems, International Journal of Production Economics, Mathematics and Computers in Simulation, Fuzzy Sets and Systems, Omega, Knowledge-Based Systems, International Journal of Information Technology & Decision Making, Computers in Industry etc*. The majority of articles on MCDM have been published since 2000; as a result, this year was chosen as the starting date for this study. It is noticeable that since online database access point is limited, some articles could not be downloaded; for that reason, they were overlooked in this survey. After reviewing each article, the article was summarised and highlighted. An article is taken into consideration in this review if it discusses thoroughly the application and development of MCDM.

MCDM is the most well-known branches of DM. In the DM approach, the selection is made from amongst the decision alternatives that are described by their attributes. Over time, a large number of MCDM techniques and approaches have been proposed, which are different in their theoretical background, the type of questions asked, and the type of obtained results. For a given problem, a number of methods have been particularly proposed, which cannot be applied to other problems. Several keywords and criteria should be taken into account for the selection of an MCDM method. In this

review article, to identify the scholarly articles related to DM methods in the database, we have searched using several keywords, they were: MCDM, DM, AHP, COPRAS, TOPSIS, VIKOR, ELECTRE, MULTIMOORA, DEMATEL, SWARA, ANP, MOORA, PROMETHEE, WASPAS, SAW, FDM, ARAS, Entropy, Hybrid MCDM, and so on. After a preliminary search and collecting these scholarly articles, those relating to DM techniques and approaches were selected.

4. Results

4.1. Classifications and observations

This article is based on a literature review and classification of international journal articles from 2000 to 2014. The majority of the journals are specialist journals in the MCDM area. For the purpose of this part of the article, some of journals are listed based on publishers, and some journals (e.g. Web of Science database) are integrated based on their publishers.

Research on MCDM continued and found many applications to different fields. MCDM provides strong DM in domains where selection of the best alternative is highly complex. This article reviews the main streams of considerations in MCDM theory and practice in detail, and we aimed to identify various applications and approaches and suggest approaches that can be most robustly and effectively used to identify the best alternative. This survey also addresses the problems in MCDM techniques. MCDM method has been applied to many domains to choose the best alternatives. Where many criteria have come into existence, the best one can be obtained by analysing different scopes of the criteria, weights of the criteria, and the selection of the optimum ones using any MCDM techniques.

This article investigates the developments of various methods of MCDM and its applications. In our daily life, many decisions are made based on various criteria; thus the decision can be made by assigning weights to different criteria and all the weights are obtain from expert groups. It is important to determine the structure of the problem and explicitly evaluate multi-criteria. For example, in building a nuclear power plant, certain decisions have been taken based on different criteria. There are not only very complex issues involving multi-criteria, some criteria may have an effect on some problems; however, to have an optimum solution, all alternatives must have common criteria, which clearly lead to more informed and better decisions. The AHP method is used in the analysis of the health-safety and environmental risk assessment of refineries for the location of the power plant, the risk factors such as health-safety risk, technology risk, etc. (Rezaian & Jozi, 2012). TOPSIS has been applied to the selection of the best strategic technology for the fuel cell in the automotive industry (Sadeghzadeh & Salehi, 2011).

In all these articles, different methods have been used for different applications where each method has its own characteristics in finding the best alternatives. The applications developed to solve multi-choice problems and the selected MCDM methods provide better performance in cases such as Energy, environment and sustainability, Supply chain management, Material, Quality management, GIS, construction and project management, safety and risk management, manufacturing systems, technology management, operation research and soft computing, strategic management, knowledge management, production management, tourism management and other fields. Table 1 presents the distribution of articles based on application fields.

Table 1. Distribution papers based on application areas.

Application fields	Number of paper	Percentage
Energy, environmental and sustainability	53	13.49
Supply chain management	23	5.85
Material	21	5.34
Quality management	12	3.05
GIS	14	3.56
Construction and project management	18	4.58
Safety and risk management	14	3.56
Manufacturing systems	32	8.14
Information technology management	25	6.36
Operation research and soft computing	109	27.74
Strategic management	8	2.04
Knowledge management	5	1.27
Production management	18	4.58
Tourism management	11	2.80
Other fields	30	7.63
Total	**393**	**100**

Source: Authors' calculation.

4.2. Field of category

Due to wide range of applications of MCDM in the real world, there is a strong motivation to categorise these applications across several areas and particular sub-areas. The studies that have used MCDM are categorised into three groups: MCDM utilising research, MCDM developing research, and MCDM proposing research. To identify the differences and similarities, the 393 articles were categorised into the 15 fields we have previously mentioned. In cases of articles that could fall into more than one category, based on the targeted audience defined by the article's objectives, the best possible choice was selected. This ensured the absence of any duplication in the classification scheme. In the following sections, the articles are briefly presented and each topic is further summarised using tables corresponding to their sub-areas. In each table, the articles are summarised and highlighted according to their introductions, research methods, and the results of the study. Similarly, previous studies (e.g., Behzadian, Khanmohammadi Otaghsara, Yazdani, and Ignatius (2012)) have categorised TOPSIS articles based on area of applications like manufacturing systems, supply chain issue, business and management, human resource management, energy and safety, environmental science and so on.

4.3. GIS, IT management and material science

In fields of GIS, IT management and material science various scholars have employed MCDM techniques and approaches. These fields involve several particular sub-fields including; GIS; landslide susceptibility mapping (Yalcin, Reis, Aydinoglu, & Yomralioglu, 2011), ArcGIS (Marinoni, 2004), GIS-based solar farms site (Uyan, 2013), in the field of IT management, information technology (Oztaysi, 2014), technology network (Lee, Kim, & Park, 2009), information service (Chen & Wang, 2010) and field of material science (Jahan, Mustapha, Ismail, Sapuan, & Bahraminasab, 2011; Cavallini, Giorgetti, Citti, & Nicolaie, 2013; Chatterjee, Athawale, & Chakraborty, 2009; Chatterjee, Athawale, &

Chakraborty, 2011; Shanian, Milani, Carson, & Abeyaratne, 2008; Mayyas et al., 2011). In these fields of applications, a total of 52 articles have applied MCDM techniques and approaches, GIS is 13 articles (3.27%), material science, 18 articles (4.52%) and IT 21 articles (5.28%).

4.4. Operation research, soft computing and other fields

In fields of operation research and soft computing some of previous studies have developed, proposed and presented the MCDM techniques and approaches. Most of these previous studies have attempt to solving problems in DM techniques and approaches. For example in case of developed AHP technique; (Lin, Wang, Yu, 2008; Lai, Wang, Wang, 2008; Hu & Tsai, 2006; Bortot & Marques Pereira, 2013), in the case of the TOPSIS method (Liu, Chan, & Ran, 2013; Shidpour, Shahrokhi, & Bernard, 2013; Jahanshahloo, Lotfi, & Izadikhah, 2006a; Zhang & Yu, 2012; Baky, 2014; García-Cascales & Lamata, 2012), DEMATEL technique (Li & Tzeng, 2009), ELECTRE (Figueira, Greco, Roy, & Słowiński, 2013), (Leyva-López & Fernández-González, 2003), PROMETHEE (Zhang, Fan, & Liu, 2010; Ishizaka & Nemery, 2011; Hu, 2010), ANP (Khademi, Mohaymany, Shahi, Zerguini, 2012; Lin, Chen, & Ting, 2010), and VIKOR (Sayadi, Heydari, & Shahanaghi, 2009; Ju & Wang, 2013; Liu, Mao, Zhang, & Li, 2013). Operation research and soft computing fields had the first rank in these categories, in these fields; 109 previous scholars (27.74%) have applied MCDM techniques and approaches.

4.5. Energy, environment and sustainability field

According to our review in fields of energy, environment and sustainability 55 studies (13.45%) have used MCDM techniques and approaches. Energy, environment and sustainability fields involve several specific sub-fields, some recent applications of MCDM approaches, including energy polices (Abid & Bahloul, 2011), energy resource planning (Erol & Kılkış, 2012), and renewable energy (Papadopoulos & Karagiannidis, 2008). In the environment field, environmental factors (Hasanzadeh, Danehkar, & Azizi, 2013), environmental production (Lin, Cheng, Tseng, & Tsai, 2010), environmental management system (Sambasivan & Fei, 2008), eco-environmental quality (Ying et al., 2007). In the field of sustainability: risk sustainability (Stankevičienė, Sviderskė, & Miečinskienė, 2014), government sustainability (Bilbao-Terol, Arenas-Parra, Cañal-Fernández, & Antomil-Ibias, 2014), transport sustainability (Bojković, Anić, & Pejčić-Tarle, 2010), sustainable flooring systems (Reza, Sadiq, & Hewage, 2011) and hydrogen sustainability (Ren, Manzardo, Toniolo, & Scipioni, 2013).

4.6. Supply chain, quality, production management and manufacturing systems field

Some previous scholars have applied MCDM techniques and approaches in fields on supply chain management, quality management, production management and manufacturing systems. These fields involve several specific sub-fields and sub-areas, in total 94 articles (22.74%) have used MCDM techniques and approaches, some recent publications in field of supply chain management including; supplier performance (Kang & Lee, 2010), supplier selection (Bruno, Esposito, Genovese, & Passaro, 2012; Huang, Tong, Chang, & Yeh, 2011), supplier quality (Ho, Feng, Lee, & Yen, 2012), logistic suppliers (Chen, Pai, & Hung, 2010), process of supply chain (Kirytopoulos, Leopoulos,

& Voulgaridou, 2008), sustainable supply chain management (Büyüközkan & Berkol, 2011). In the quality management field, service quality (Liou, Tsai, Lin, & Tzeng, 2011), quality indexes (Tong, Kwong, & Ip, 2003), quality parameters (Ghosh & Das, 2013), quality of learning (Kurilovas & Zilinskiene, 2013). In the field of production management, the production of thin-film (Cavallaro, 2010), production technologies (Streimikiene, Balezentis, Krisciukaitienė, & Balezentis, 2012), mass production (Chang, Hu, & Hong, 2013). In the manufacturing systems field are; the manufacturing sector (Bagočius, Zavadskas, & Turskis, 2014), manufacturing systems (Jana, Bairagi, Paul, Sarkar, & Saha, 2013), global manufacturing (Tzeng & Huang, 2012), and manufacturing strategy (Yurdakul, 2004).

4.7. Strategic, knowledge and tourism management field

In the field of knowledge management, strategic management and tourism management, some previous studies (5.86%) have published articles in different fields of MCDM techniques and approaches. Knowledge management, strategic management and tourism management involve several specific sub-fields, some recent applications of MCDM approaches in including, knowledge management (Li, Jin, & Wang, 2014; Carlucci & Schiuma, 2009; Kanapeckiene, Kaklauskas, Zavadskas, & Seniut, 2010; Chu, Shyu, Tzeng, & Khosla, 2007). In the field of strategic management (Baležentis & Baležentis, 2011; J. J. Liou, 2012; Sadeghzadeh & Salehi, 2011). In the tourism management field Liu, Tzeng, and Lee (2012), Bunruamkaew and Murayam (2011), and Hsieh, Lin, and Lin (2008), The results of Table 1 indicated that, in total 24 articles have published in these field and sub-fields.

4.8. Construction, project, safety and risk management field

Results of Table 1 showed that, in fields of construction management, project management, safety and risk management 37 articles (9.05%) have applied an MCDM approach and techniques. Construction management, project management, safety and risk management involve several specific sub-fields, some recent applications of MCDM approaches include: construction management (Zavadskas, Turskis, Volvačiovas, & Kildiene, 2013; Zavadskas, Skibniewski, & Antucheviciene, 2014; Kanapeckiene et al., 2010; Brauers, Kildienė, Zavadskas, & Kaklauskas, 2013; Gudienė, Banaitis, Podvezko, & Banaitienė,

Table 2. Summary of applications of the DM techniques.

DM techniques	Frequency of application	Percentage
AHP	128	32.57
ELECTRE	34	8.65
DEMATEL	7	1.78
PROMETHEE	26	6.62
TOPSIS	45	11.4
ANP	29	7.38
Aggregation DM methods	46	11.70
Hybrid MCDM	64	16.28
VIKOR	14	3.56
Total	393	100.00

Source: Authors' calculation.

2014) in field of project management (Buchanan & Vanderpooten, 2007; Mohammadi, Sadi, Nateghi, Abdullah, & Skitmore, 2014; Zavadskas, Turskis, Tamošaitiene, & Marina, 2008), in the area of risk management (Jiang, Hu, & Jin, 2007; Wabiri & Amusa, 2010), and in fields of safety (Liu, Mao, Li, & Yao, 2007; Wang, Qin, Li, & Chen, 2009; Chen, Jin, Qiu, & Chen, 2014; Dėjus & Antuchevičienė, 2013).

4.9. Distribution based on MCDM techniques and approaches

Table 2 shows frequency of MCDM techniques and approaches. Based on the results presented in this table, a total of 393 studies have employed DM techniques and approaches. This table shows that AHP method (32.57%), and its applications have been used more than other tools and approaches. The second one is the hybrid MCDM techniques and approaches (16.28%) and DM aggregation methods (11.70%) are the third in this ranking. The frequency of other tools and approaches are presented in Table 2. All tables sorted articles alphabetically by author name.

Table 3. Distribution based on AHP.

Authors	Year	Type of study	Tools and approaches
(Yalcin, Reis, Aydinoglu, & Yomralioglu)	2011	Utilised research	Evaluated of landslide susceptibility mapping by utilised AHP and GIS
(Abba, Noor, Yusuf, Din, & Hassan)	2013	Utilised research	Used AHP for assessment of environmental impacts of solid waste disposal
(Abid & Bahloul)	2011	Utilised research	Employed AHP for determine the attractiveness factors
(Aguilar-Lasserre, Bautista Bautista, Ponsich, & González Huerta)	2009	Utilised research	Utilised AHP for problem solving in selection of tool for the batch plant design
(Al Khalil)	2002	Utilised research	Selected the best project delivery by utilised AHP
(Al-Harbi)	2001	Utilised research	Project management evaluation by utilised AHP
(Yalcin)	2008	Utilised research	Applied AHP for three susceptibility maps
(Rezaei & Ortt)	2013	Utilised research	Applied AHP for evaluation of supplier segmentation
(Aminbakhsh, Gunduz, & Sonmez)	2013	Utilised research	Assessed of safety risk factors by used AHP
(Ataei, Shahsavany, & Mikaeil)	2013	Developed research	Determined the level of confidence of each alternative's score by used AHP
(Ayağ)	2005	Utilised research	Evaluated of conceptual design in a NPD environment by used AHP
(Azadeh, Ghaderi, & Izadbakhsh)	2008	Utilised research	Integrated of AHP for improve of the railway system
(Barker & Zabinsky)	2011	Utilised research	Employed AHP for assessment of reverse logistics
(Benítez, Delgado-Galván, Izquierdo, & Pérez-García)	2012	Developed research	Improved AHP based on pairwise comparisons with numerical judgements

(*Continued*)

Table 3. (*Continued*).

Authors	Year	Type of study	Tools and approaches
(Bentes, Carneiro, da Silva, & Kimura)	2012	Utilised research	Utilised AHP for performance assessment based on BSC framework
(Bertolini, Braglia, & Carmignani)	2006	Utilised research	Best discount selection in defining of proposal by used AHP
(Bortot & Marques Pereira)	2013	Developed research	Extended of the standard AHP aggregation scheme
(Altuzarra, Moreno-Jiménez, & Salvador)	2007	Proposed research	Proposed AHP-GDM for solving problems in DM tools
(Bernasconi, Choirat, & Seri)	2014	Developed research	Used Aggregation approaches in the AHP for classification based on algebraic properties
(Brent, Rogers, Ramabitsa-Siimane, & Rohwer)	2007	Utilised research	Sustainable development by used AHP for health care waste management systems
(Brunelli, Critch, & Fedrizzi)	2013	Developed research	Employed AHP for proportionality between some consistency indices
(Bruno, Esposito, Genovese, & Passaro)	2012	Utilised research	Evaluated of supplier based on AHP method
(Bunruamkaew & Murayam)	2011	Utilised research	Implemented AHP for evaluation of ecotourism sites
(Buyurgan & Saygin)	2008	Utilised research	Assessed advanced manufacturing systems by utilised for part routing and real-time scheduling
(Lee, Lee, Seol, & Park)	2012	Utilised research	Implemented AHP for assessment of new service concepts (NSCs)
(Chen)	2014	Utilised research	Assessment of tourism festival activities with AHP
(e Costa & Vansnick)	2008	Developed research	Used derived ranking in AHP for critical analysis of the eigenvalue method
(Lin, Wang, & Yu)	2008	Developed research	Adopted AHP for soft computing scheme and genetic Algorithms
(Chang, Wu, Lin, & Chen)	2007	Utilised research	Employed AHP for manufacturing quality in order to forecasting programmes
(Cay & Uyan)	2013	Utilised research	Evaluated of reallocation in land consolidation by used AHP
(Chan, Ip, & Lau)	2001	Utilised research	Utilised AHP for favourable equipment type
(Chinese, Nardin, & Saro)	2011	Utilised research	Space heating systems selection by utilised AHP
(Chwolka & Raith)	2001	Developed research	Extended different group preference aggregation approaches used in the AHP for solving problems DM issues
(Daim, Udbye, & Balasubramanian)	2012	Utilised research	Used AHP for selection of 3PL provider
(De Feo & De Gisi)	2010	Utilised research	Assessed of stakeholders involvement for ranking suitable MSW facility sites by utilised AHP
(Di Gironimo, Carfora, Esposito, Labate, Mozzillo, Renno, Lanzotti, & Siuko)	2013	Utilised research	Evaluation of RH system by employed AHP and TRIZ
(Dong, Hong, Xu, & Yu)	2013	Proposed research	presented an algorithm for achieve the linguistic individual in AHP

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Table 3. (*Continued*).

Authors	Year	Type of study	Tools and approaches
(Effat & Hassan)	2013	Utilised research	Evaluated of economic and environmental by utilised AHP
(Entani & Sugihara)	2012	Proposed research	Proposed the models to achieve intervals of attributes based on AHP
(Erol & Kılkış)	2012	Utilised research	Used AHP for activities of facilitate energy resource planning
(Wang, Qin, Li, & Chen)	2009	Utilised research	Used AHP for solving problem in selection of solid waste landfill site
(Gass & Rapcsák)	2004	Proposed research	Proposed new method to determine of associated weights in SVD based on AHP
(Ghosh & Das)	2013	Utilised research	Evaluation of jute fibres quality parameters by used AHP
(Gudienė, Banaitis, Podvezko, & Banaitienė)	2014	Utilised research	Identified and assessed of construction projects CSFs by used AHP
(Kou & Lin)	2014	Developed research	Proposed CM method based on the similarity measure in AHP
(Kang & Lee)	2010	Utilised research	Evaluation of supplier performance by utilised AHP
(Hajeeh & Al-Othman)	2005	Utilised research	Employed AHP for selection of technology for seawater desalination
(Handfield, Walton, Sroufe, & Melnyk)	2002	Utilised research	Employed AHP to help understand of the managers in trade-offs of environmental
(Hongwei, Zhanpeng, Shaoqi, & Ruihua)	2004	Utilised research	Assessed of the anaerobic biodegradability by used AHP
(Huang, Tong, Chang, & Yeh)	2011	Utilised research	Supplier selection by employed AHP
(Huo, Lan, & Wang)	2011	Developed research	Improved AHP by used a new parametric prioritisation method
(Ic, Yurdakul, & Eraslan)	2012	Utilised research	Implemented AHP for machine-selection
(Ivlev, Kneppo, & Bartak)	2014	Utilised research	Medical equipment selection by used AHP
(Jiang, Hu, & Jin)	2007	Utilised research	Used AHP for assessment of economic risk in real estate project
(Jovanovic, Krivokapic, & Vujovic)	2013	Utilised research	Applied AHP for assessment of environmental impacts
(K. Xu, Kong, Li, Zhang, & Wu)	2011	Utilised research	Implemented of AHP for evaluation of geological factors
(Kallas & Gil)	2012	Utilised research	Applied AHP for derive the WTP for complex goods
(Kallas, Lambarraa, & Gil)	2011	Utilised research	Used AHP for compared individual preferences for attributes and levels of an agro-food product
(Kayastha, Dhital, & De Smedt)	2013	Utilised research	Assessed landslide susceptibility map by employed AHP
(Kildienė, Zavadskas, & Tamošaitienė)	2014	Utilised research	Used AHP for evaluation of advanced technology deployment

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Table 3. (*Continued*).

Authors	Year	Type of study	Tools and approaches
(Konidari & Mavrakis)	2007	Utilised research	Utilised AHP for defining coefficients weights for criteria and sub-criteria in stockholders groups
(Kurilovas & Zilinskiene)	2013	Proposed research	Presented MCEQLS AHP for the expert evaluation of quality of learning scenarios
(Lai, Wang, & Wang)	2008	Utilised research	Applied AHP for evaluation of budgets in construction project
(Lai, Wong, & Cheung)	2002	Utilised research	Used AHP for selection of software
(Liao & Kao)	2010	Utilised research	Solving supplier selection problems by integrated AHP, Taguchi loss function and goal programming
(Chen & Wang)	2010	Utilised research	Applied for evaluation of six business models
(Lin, Lee, & Ho)	2011	Utilised research	Developed economic by used AHP
(Mahdi & Alreshaid)	2005	Utilised research	Selection of the proper delivery by used AHP
(Millet & Saaty)	2000	Proposed research	Proposed procedures for choose of synthesis mode
(Yavuz, Iphar, & Once)	2008	Utilised research	Employed AHP for selection the best support design for the main transport road
(Beynon)	2005	Developed research	Investigated of the non-specificity and local ignorance measures by utilised AHP
(Beynon)	2002a	Developed research	Developed DS/AHP with respect to the measurement for understands of uncertainty
(Beynon)	2002b	Developed research	Used AHP for analysis of distributions
(Manca & Brambilla)	2011	Utilised research	Used AHP for activity assessment
(Maniya & Bhatt)	2011	Proposed research	Proposed AHP/M-GRA model for the selection of AGV alternative
(Marinoni)	2004	Utilised research	Developed of an ArcGIS VBA macro by applied AHP
(Mau-Crimmins, de Steiguer, & Dennis)	2005	Utilised research	Used AHP for assessment of national forest planning situation
(Mayyas, Shen, Mayyas, abdelhamid, Shan, Qattawi, Omar)	2011	Utilised research	Selected of material by implemented of AHP
(Mishra, Khasnabis, & Swain)	2013	Utilised research	Employed of AHP for feasibility of strategies
(Moeinaddini, Khorasani, Danehkar, Darvishsefat, & zienalyan)	2010	Utilised research	Used AHP spatial auto-correlation of the land suitability map layer
(Mohajeri & Amin)	2010	Utilised research	Employed AHP for optimum site off railway station

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Table 3. (*Continued*).

Authors	Year	Type of study	Tools and approaches
(Nigim, Suryanarayanan, Gorur, & Farmer)	2003	Utilised research	Determined special protection schemes (SPS) failures in a power system by AHP
(Nikou & Mezei)	2013	Utilised research	Employed AHP for mobile services in order to driving the adoption
(Oddershede, Arias, & Cancino)	2007	Developed research	Rural development for improved AHP
(Ojha, Das, Mondal, & Maiti)	2010	Utilised research	Solved problem in solid transportation by utilised AHP
(Ong, Koh, & Nee)	2001	Utilised research	Employed AHP for derive a single environmental score
(Orencio & Fujii)	2013	Utilised research	Employed AHP for reduce the vulnerability of coastal
(Othman, Repke, & Wozny)	2010	Utilised research	Implemented of AHP for rank of sustainable chemical process design
(Hsu & Chen)	2008	Utilised research	Criteria selection from pertinent literature by employed AHP
(Padma & Balasubramanie)	2009	Developed research	Developed AHP for build a KBDSS that assist to overcome problem
(Perez-Vega, Peter, Salmeron-Ochoa, Nieva-de la Hidalga, & Sharratt)	2011	Utilised research	Employed AHP for pharmaceutical process development
(Podvezko & Sivilevičius)	2013	Utilised research	Used of AHP for methodology of the logical control in filling of the questionnaire
(Ramanathan)	2007	Utilised research	Used AHP for subjective and objective information
(Ramesh & Kodali)	2012	Utilised research	Assessment of lean manufacturer performance by utilised AHP
(Ren, Manzardo, Toniolo, & Scipioni)	2013	Utilised research	Employed AHP for classify and ranking of hydrogen sustainability in supply chains
(Reza, Sadiq, & Hewage)	2011	Utilised research	Assessment of sustainability flooring systems by employed AHP
(Roig-Tierno, Baviera-Puig, Buitrago-Vera, & Mas-Verdu)	2013	Utilised research	Retail site location selection by utilised AHP
(Rousos & Lee)	2012	Utilised research	Utilised AHP for evaluation of shipping investment
(Chen)	2009	Utilised research	Employed of AHP for intellectual capital of e-learning for competitive advantages
(Sabharwall, Kim, & Patterson)	2012	Utilised research	Applied AHP for evaluation of generation in nuclear reactors
(Sadeghi & Ameli)	2012	Utilised research	Applied AHP for sectoral allocation of energy subsidy
(Safari, Ataei, Khalokakaie, & Karamozian)	2010	Utilised research	Utilised AHP for selection of plant location
(Sahin, Mohamed, Warnken, & Rahman)	2013	Utilised research	Applied AHP for improve Gold Coast's resilience for climate change

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Table 3. (*Continued*).

Authors	Year	Type of study	Tools and approaches
(Sambasivan & Fei)	2008	Utilised research	Used AHP for ranking of environmental management system CSFs
(Şener, Şener, Nas, & Karagüzel)	2010	Utilised research	Employed AHP and GIS for selection of landfill site
(Shen, Muduli, & Barve)	2013	Utilised research	Utilised AHP for competitive ranking of GSCM implementation
(Tang)	2011	Utilised research	Used AHP to evaluating and planning for ESL programmes
(Tian, Bai, Sun, & Zhao)	2013	Utilised research	Evaluated process of sustainability for coastal beach by used AHP
(Triantaphyllou)	2001	Developed research	Developed AHP for problems solving in DM techniques
(Uyan)	2013	Utilised research	Election of suitable sites for solar farms by utilised AHP
(Venkata Rao)	2004	Utilised research	Selections of strip-layout procedure for metal die stamping work by used AHP
(Vinodh, Shivraman, & Viswesh)	2011	Utilised research	Evaluated of lean manufacturing systems by used AHP
(Wang, Yu, Yang, Lin, Lee, & Cheng)	2013	Utilised research	Selection of BV contractors in construction projects by applied AHP
(Wabiri & Amusa)	2010	Utilised research	Used AHP for energy policies and geopolitics for oil producers
(Wong & Li)	2008	Developed research	Assigned and ranked the important weightings for the perceived criteria by applied AHP
(Zhu & Dale)	2001	Utilised research	Used AHP for problem solving on the World Wide Web
(Chen, Yu, & Khan)	2010	Utilised research	Analysis MCDM criteria weight sensitivity based on GIS-based AHP-SA
(Chen, Yu, & Khan)	2010	Utilised research	Evaluation of environment-friendly impact based on transport measures by used AHP
(Hu & Tsai)	2006	Developed research	Applied AHP for back propagation multi-layer perceptron
(Liu, Mao, Li, & Yao)	2007	Utilised research	Assessed of safety systems by used AHP
(Wang & Chin)	2009	Proposed research	Proposed new DEA for priority determination in the AHP
(Dong, Xu, Li, & Dai)	2008	Developed research	Presented two performance measurements for evaluation of prioritisation methods and numerical scales based on AHP
(Zhang, Deng, Wei, & Deng)	2012	Utilised research	Employed AHP for evaluation of E-Commerce security
(Ying, Zeng, Chen, Tang, Wang, & Huang)	2007	Utilised research	Used AHP for evaluation of synthetically eco-environmental quality
(Zhang, Sun, & Qin)	2012	Utilised research	Assessment of sustainable development by applied AHP
(Zangeneh, Jadid, & Rahimi-Kian)	2009	Utilised research	Ranking and evaluation of DG technologies by used AHP

Source: Authors' calculation.

Table 4. Distribution based on PROMETHEE.

Authors	Year	Type of study	Tools and approaches
(Abedi, Ali Torabi, Norouzi, Hamzeh, & Elyasi)	2012	Utilised research	Applied PROMETHEE II for produce the desired MPM
(Abedi, Gholami, & Norouzi)	2013	Utilised research	Employed PROMETHEE II for assessment of applied to geological layers, airborne geophysical data, and remote sensing images
(Albadvi)	2004	Utilised research	Strategic selection for application flagships by employed PROMETHEE
(Albadvi, Chaharsooghi, & Esfahanipour)	2007	Utilised research	Stock trading assessment by applied PROMETHEE
(Araz, Mizrak Ozfirat, & Ozkarahan)	2007	Utilised research	Applied PROMETHEE for selection of suitable outsourcers for the strategic partners
(Chen, Pai, & Hung)	2010	Utilised research	Ranking of logistic suppliers by used PROMETHEE
(Chou, Lin, Lin, Chou, & Huang)	2004	Utilised research	Employed PROMETHEE for selection of depression outlet location
(Corrente, Figueira, & Greco)	2014	Developed research	Applied the SMAA for solving problems in DM based on the PROMETHEE
(de Almeida & Vetschera)	2012	Developed research	Corrected portfolio problems by using PROMETHEE V
(Dhouib & Elloumi)	2011	Developed research	Proposed integrated methods for multi-criteria analysis by used PROMETHEE
(Ghafghazi, Sowlati, Sokhansanj, & Melin)	2010	Utilised research	Used PROMETHEE for ranking of energy options
(Ishizaka & Nemery)	2011	Utilised research Utilised research	Selection the statistical distribution by used PROMETHEE
(Beynon & Wells)	2008	Utilised research	Used PROMETHEE for lean improvement in the chemical emissions
(Kadziński, Greco, & Słowiński)	2012b	Proposed research	Proposed PROMETHEE^{GKS} based on Robust ordinal regression
(Oberschmidt, Geldermann, Ludwig, & Schmehl)	2010	Utilised research	Assessed of technology's life cycle by employed PROMETHEE
(Queiruga, Walther, González-Benito, & Spengler)	2008	Utilised research	Site location assessment for WEEE recycling plants by applied PROMETHEE
(Rousis, Moustakas, Malamis, Papadopoulos, & Loizidou)	2008	Utilised research	Evaluated of WEEE management system by used PROMETHEE
(Parreiras & Vasconcelos)	2007	Developed research	Improved PROMETHEE II for solving problems of multiobjective optimisation
(Tsoutsos, Drandaki, Frantzeskaki, Iosifidis, & Kiosses)	2009	Utilised research	Applied for PROMETHEE I and PROMETHEE II energy planning issues
(Vetschera & De Almeida)	2012	Utilised research	Employed PROMETHEE for solving problem in selection of portfolio
(Vinodh & Jeya Girubha)	2012	Utilised research	Selected the best sustainable concept by employed PROMETHEE
(Waeyenbergh, Vannieuwenhuyse, & Pintelon)	2004	Utilised research	Used PROMETHEE for solve problem in predictive maintenance programme

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Table 4. (*Continued*).

Authors	Year	Type of study	Tools and approaches
(Hu & Chen)	2011	Developed research	Developed PROMETHEE for multi-criteria classification problems
(Hu)	2010	Developed research	Developed a new PROMETHEE II-based SLP using concepts from the PROMETHEE II
(Zhang, Fan, & Liu)	2010	Developed research	Developed PROMETHEE to obtain the ranking result of alternatives

Source: Authors' calculation.

Table 5. Distribution based on ELECTRE.

Authors	Year	Type of study	Tools and approaches
(Shanian, Milani, Carson, & Abeyaratne)	2008	Utilised research	Selection of material by used ELECTRE III
(Beccali, Cellura, & Mistretta)	2003	Utilised research	Implemented of ELECTRE for technology assessment of renewable energy
(Bisdorff)	2002	Proposed research	Proposed ELECTRE-like method for clustering judges
(Bojković, Anić, & Pejčić-Tarle)	2010	Utilised research	Evaluated of transport-sustainability by utilised ELECTRE
(Bouyssou & Marchant)	2007	Developed research	Developed ELECTRE TRI for sorting models problems
(Bouyssou & Pirlot)	2009	Proposed research	Used conjoint measurement for achieve axiomatic characterisation of preference relations such as ELECTRE
(Brito, de Almeida, & Mota)	2010	Proposed research	Proposed a multi-criteria model for risk assessment in natural gas pipelines based on ELECTRE and Utility Theory
(Buchanan & Vanderpooten)	(2007)	Utilised research	Project selection by employed ELECTRE III
(Cavallaro)	(2010)	Utilised research	Assessed of processes in the production of thin-film photovoltaic
(Dias & Mousseau)	2006	Proposed research	Presented a partial inference process to compute the value of the veto-related parameters based on ELECTRE
(Dias, Mousseau, Figueira, & Clímaco)	2002	Proposed research	Developed ELECTRE TRI based on interactive aggregation–disaggregation approach to achieve robust conclusions
(Doumpos, Marinakis, Marinaki, & Zopounidis)	2009	Developed research	Proposed evolutionary approach in the ELECTRE environment
(Figueira, Greco, & Roy)	2009	Developed research	Extended of the concordance index for ELECTRE methods
(Figueira & Roy)	2002	Developed research	Developed ELECTRE based on revised Simos

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Table 5. (*Continued*).

Authors	Year	Type of study	Tools and approaches
(Georgopoulou, Sarafidis, Mirasgedis, Zaimi, & Lalas)	2003	Utilised research	Applied ELECTRE III for greenhouse gases emissions reduction
(Greco, Kadziński, Mousseau, & Słowiński)	2011	Proposed research	Proposed new ELECTRE^{GKMS} for robust ordinal regression
(Giannoulis & Ishizaka)	2010	Utilised research	Used ELECTRE III for British universities ranking
(Iniestra & Gutiérrez)	2009	Utilised research	Applied ELECTRE III for evaluation of transportation projects
(Ishizaka & Nemery)	2014	Utilised research	Developed ELECTRE-SORT for strategies of maintenance
(Leyva-López & Fernández-González)	2003	Developed research	Extended the ELECTRE III for solving problems to assist group of decision-makers
(Li & Sun)	2009	Proposed research	Proposed new model based on ELECTRE-CBR-I and ELECTRE-CBR-II
(Lourenço & Costa)	2004	Proposed research	Proposed interactive 'branch-and-bound like' for progressively build the nondominated set and combined with ELECTRE TRI
(Martin, Ruperd, & Legret)	2007	Utilised research	Applied ELECTRE III for evaluation of the best management practice
(Taillandier & Taillandier)	2012	Utilised research	Developed ELECTRE III for solving MCDM problems with imprecise data
(Mousseau & Dias)	2004	Developed research	Adapted slight of the relation of valued outranking used in the ELECTRE TRI and ELECTRE III
(Mousseau, Figueira, & Naux)	2001	Developed research	Developed ELECTRE TRI based on interactive aggregation–disaggregation
(Huck)	2010	Proposed research	Evaluated of Pairs trading based on Neural Networks and ELECTRE III
(Norese)	2006	Utilised research	Employed ELECTRE III for waste-treatment plants localisation
(Papadopoulos & Karagiannidis)	2008	Utilised research	Decentralised energy systems by used ELECTRE III
(Roy & Słowiński)	2008	Developed research	Proposed computing the credibility of outranking in multi criteria aggregation process such as ELECTRE
(Sánchez-Lozano, Henggeler Antunes, García-Cascales, & Dias)	2014	Utilised research	Applied ELECTRE-TRI and GIS for selection of photovoltaic solar farms site
(Figueira, Greco, Roy, Słowiński)	2013	Developed research	Presented and discuss the features of ELECTRE
(Ulubeyli & Kazaz)	2009	Utilised research	Employed ELECTRE III for solve problem in selection of concrete pumps
(Tervonen, Figueira, Lahdelma, Dias, & Salminen)	2009	Proposed research	Proposed SMAA-TRI method based on ELECTRE TRI in sorting problems

Source: Authors' calculation.

Table 6. Distribution based on TOPSIS.

Authors	Year	Type of study	Tools and approaches
(Baky & Abo-Sinna)	2013	Proposed research	Presented TOPSIS for solving problems in bi-level MODM tools
(Baky)	2014	Developed research	Improved TOPSIS for solving problem in MLN-MODM methods
(Bilbao-Terol, Arenas-Parra, Cañal-Fernández, & Antomil-Ibias)	2014	Utilised research	Government sustainability assessment by employed TOPSIS
(Cheng)	2008	Proposed research	Presented the effective approach by adopt TOPSIS for solving MCDM problems
(Dadelo, Turskis, Zavadskas, & Dadeliene)	2014	Utilised research	Sport team formation ranking and evaluation by used TOPSIS
(Du, Gao, Hu, Mahadevan, & Deng)	2014	Utilised research	Applied TOPSIS for identifying nodes in complex networks
(Dymova, Sevastjanov, & Tikhonenko)	2013	Developed research	Extended on TOPSIS based on direct interval
(García-Cascales & Lamata)	2012	Proposed research	Proposed modifications in the algorithm of Hwang and Yoon TOPSIS method
(Li, Adeli, Sun, & Han)	2011	Utilised research	Applied TOPSIS for prediction of binary business failure
(Zhang & Yu)	2012	Developed research	Extended TOPSIS for ranking of all the alternatives
(İç)	2012	Proposed research	Applied TOPSIS for solving problems in selection of CIM
(İç)	2014	Utilised research	Employed TOPSIS for assessment of company ranking
(Jadidi, Hong, & Firouzi)	2009	Developed research	Applied TOPSIS for solve problem of the MOMILP
(Jadidi, Sai Hong, Firouzi, & Yusuff)	2009	Proposed research	Proposed a new TOPSIS in grey theory to deal with the suppliers' selection problem
(Jahanshahloo, Lotfi, & Izadikhah)	2006a	Developed research	Extended the TOPSIS for DM problems with interval data
(Jahanshahloo, Hosseinzadeh Lotfi, & Davoodi)	2009	Proposed research	Presented a new TOPSIS for ranking of DMUs
(Jahanshahloo, Khodabakhshi, Hosseinzadeh Lotfi, & Moazami Goudarzi)	2011	Developed research	Presented a new super-efficient for rank of decision-making units based on TOPSIS
(Kao)	2010	Developed research	Improved TOPSIS for solving problem in MCDA methods
(Karimi-Nasab & Seyedhoseini)	2013	Utilised research	Applied TOPSIS for ranking of performance indexes in the job shop environment
(Kou, Peng, & Lu)	2014	Utilised research	Bank loan assessment by used TOPSIS
(Kwong & Tam)	2002	Utilised research	Applied TOPSIS for obtain of design solution of low power transformers
(Li, Jin, & Wang)	2014	Utilised research	Selection of knowledge management system by employed TOPSIS and QFD
(Lin & Yeh)	2012	Proposed research	Integrated NSGA-II and TOPSIS for evaluation of network reliability

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Table 6. (*Continued*).

Authors	Year	Type of study	Tools and approaches
(Martin, Spano, Küster, Collu, & Kolios)	2013	Developed research	Developed two methods for extend the TOPSIS capability
(Liu)	2009	Proposed research	Proposed TOPSIS for solving problem in MADM methods
(Park, Park, Kwun, & Tan)	2011	Developed research	Extend TOPSIS to solve problem in MAGDM problems
(Pazand, Hezarkhani, & Ataei)	2012	Utilised research	Employed TOPSIS and GIS for evaluation of providing prospectively maps
(Pinter & Pšunder)	2013	Utilised research	Proposed new TOPSIS-M for evaluation of construction project
(Rahman, Odeyinka, Perera, & Bi)	2012	Utilised research	Applied TOPSIS for best roofing materials selection in the market of UK housing
(Sadeghzadeh & Salehi)	2011	Utilised research	Developed fuel cell based on strategic technologies by used TOPSIS
(Shidpour et al., 2013)	2013	Utilised research	Applied TOPSIS for finding best the design of configuration product
(Shih)	2008	Developed research	Developed TOPSIS for examines the necessity of incremental analysis
(Shih, Shyur, & Lee)	2007	Developed research	Improved TOPSIS by provide new options including; normalisation, mean operators and distance measures
(Tong, Kwong, & Ip)	2003	Utilised research	Used TOPSIS for derive quality indexes in electronic packages
(Tong, Wang, Chen, & Chen)	2004	Utilised research	Employed TOPSIS for determine of performance index in multiple responses
(Tsaur)	2011	Proposed research	Presented a new TOPSIS for ranking the alternatives and normalising the collected data
(Li, Lai, & Kao)	2011	Utilised research	Applied TOPSIS for assessment of building requirement systems
(Ülengin, Kabak, Önsel, Ülengin, & Aktaş)	2010	Utilised research	Used TOPSIS for selection if the best transportation policy
(Yeh & Willis)	2001	Utilised research	Used TOPSIS for solving problem in process of winner determination
(Yue & Jia)	2013	Developed research	Determined the weights of DMs by improved TOPSIS
(Yurdakul & Ic)	2009	Utilised research	Applied TOPSIS for selection of machine tools
(Zhu, Wu, Wang, & Liang)	2012	Utilised research	Evaluated of quality credit by used TOPSIS
(Zhu, Li, Wu, Wang, & Liang)	2013	Utilised research	Applied TOPSIS for consumer credit classification
(Liu, Chan, & Ran)	2013	Developed research	Determined weights of the decision makers by extended TOPSIS method

Source: Authors' calculation.

Table 7. Distribution based on ANP.

Authors	Year	Type of study	Tools and approaches
(Agarwal, Shankar, & Tiwari)	2006	Utilised research	Applied ANP for evaluation of supply chain based on agile, lean, and agile systems
(Aragonés-Beltrán, Aznar, Ferrís-Oñate, & García-Melón)	2008	Utilised research	Used ANP for evaluation of asset valuation
(Chang, Hu, & Hong)	2013	Utilised research	Employed ANP for evaluation and ranking of agility factors
(Dou, Zhu, & Sarkis)	2014	Developed research	Developed grey ANP-based model for evaluation of green supplier development
(Wu, Lin, & Lee)	2010	Utilised research	Employed ANP for selection of competitive marketing strategy
(Lin, Chen, & Ting)	2010	Utilised research	Evaluated purchasing systems by using ANP and LP
(Erdoğmuş, Aras, & Koç)	2006	Utilised research	Employed ANP for fuels alternative in residential heating
(Erensal, Gürbüz, & Esra Albayrak)	2010	Utilised research	Competence mapping evaluation by used ANP
(Hasanzadeh, Danehkar, & Azizi)	2013	Utilised research	Employed ANP for ranking of environmental factors for selection of oil jetties sit
(Hsieh, Lin, & Lin)	2008	Utilised research	Evaluated of service quality framework by used ANP
(Ivanović, Grujičić, Macura, Jović, & Bojović)	2013	Utilised research	Used ANP for selection of road transport project
(Lee)	2010	Utilised research	Evaluated the competitive types for development of an airport by using ANP
(Khademi, Mohaymany, Shahi, Zerguini)	2012	Utilised research	Presented an algorithm for structure design based on ANP
(Khan & Faisal)	2008	Utilised research	Utilised ANP for desirability of disposal alternatives
(Kirytopoulos, Leopoulos, & Voulgaridou)	2008	Utilised research	Applied ANP for process of supply chain selection in parpharmaceutical industry
(May, Shang, Tjader, & Vargas)	2013	Developed research	Developed ANP based on stability and sensitivity of models
(Mohammadi, Sadi, Nateghi, Abdullah, & Skitmore)	2014	Utilised research	Employed ANP for selection of project manager
(Nixon, Dey, Ghosh, & Davies)	2013	Utilised research	Applied HANP for evaluation of technologies alternatives for generating electricity
(Parthasarathy & Sharma)	2014	Utilised research	Employed ANP for selection of feasible customisation in the implementation of ERP system
(Kirytopoulos, Voulgaridou, Platis, & Leopoulos)	2011	Utilised research	Applied ANP as a power matrix method for getting the limit matrix
(Kuo & Lin)	2012	Utilised research	Supplier selection by implemented of ANP
(Chen & Shyu)	2006	Utilised research	Selected weapon systems by utilising ANP
(Shiue & Lin)	2012	Utilised research	Employed ANP for evaluation of optimal strategies
(Theißen & Spinler)	2014	Utilised research	Applied ANP for the CO2 management in collaborative contexts

(*Continued*)

Table 7. (*Continued*).

Authors	Year	Type of study	Tools and approaches
(Tjader, Shang, & Vargas)	2010	Utilised research	Applied ANP for selection of the best governing policy business activities in the offshore outsourcing
(Verdecho, Alfaro-Saiz, Rodriguez-Rodriguez, & Ortiz-Bas)	2012	Utilised research	Utilised ANP for the assessment of the renewable energy sector
(Wey & Wu)	2007	Utilised research	Applied ANP for selection and assessment of a TI project
(Chang, Wey, & Tseng)	2009	Utilised research	Evaluated different revitalisation strategies by using ANP
(Lin, Chiu, & Tsai)	2008	Utilised research	Employed ANP for wafer fabrication assessment

Source: Authors' calculation.

Table 8. Distribution based on VIKOR.

Authors	Year	Type of study	Tools and approaches
(Bahraminasab & Jahan)	2011	Utilised research	Employed VIKOR for ranking materials of TKR
(Chang & Hsu)	2009	Utilised research	Applied VIKOR for ranking of land-use restraint strategies
(Cavallini, Giorgetti, Citti, & Nicolaie)	2013	Utilised research	Mixed VIKOR and QFD for material selection
(Liu, Liu, & Wu)	2013	Utilised research	Selected of materials by implemented of VIKOR method
(Liu, Liu, & Wu)	2013	Utilised research	Used VIKOR for selection of material problem under incomplete information and uncertain environment
(Liu, You, Fan, & Chen)	2014	Utilised research	Applied VIKOR for selection of site in waste management
(Liou, Tsai, Lin, & Tzeng)	2011	Utilised research	Evaluated service quality model by applied VIKOR method
(Jahan & Edwards)	2013	Utilised research	Solved materials selection problems by applied VIKOR
(Jahan, Khodabakhshi, Hosseinzadeh Lotfi, & Moazami Goudarzi)	2011	Utilised research	Applied VIKOR for optimum material selection
(Ju & Wang)	2013	Developed research	Developed VIKOR for solve MCDM problems
(Hsu)	2014	Utilised research	Applied VIKOR and Entropy for performance evaluation
(San Cristóbal)	2011	Utilised research	Applied VIKOR for Renewable Energy project selection
(Sayadi, Heydari, & Shahanaghi)	2009	Developed research	Developed VIKOR for MCOC for multi-criteria optimisation of complex systems
(Vučijak, Kupusović, Midžić-Kurtagić, & Ćerić)	2013	Utilised research	Applied VIKOR for assessment of sustainable hydropower process

Source: Authors' calculation.

Table 9. Distribution based on DM aggregation methods.

Authors	Year	Type of study	Tools and approaches
(Baležentis & Baležentis)	2011	Utilised research	Lithuanian transport efficiency assessment by using MULTIMOORA and DEA
(Alimardani, Hashemkhani Zolfani, Aghdaie, & Tamošaitienė)	2013	Utilised research	Used SWARA for evaluation of energy system sustainability for supplier selection
(Bagočius, Zavadskas, & Turskis)	2013	Utilised research	Mixed WASPAS and entropy for deep-water port selection
(Bagočius, Zavadskas, & Turskis)	2014	Utilised research	Wind turbine selection by employing WASPAS
(Balezentis & Balezentis)	2011	Utilised research	Evaluation of strategic management model by employing MULTIMOORA
(Banaitiene, Banaitis, Kaklauskas, & Zavadskas)	2008	Utilised research	Applied COPRAS for evaluation of building's life cycle
(Chakraborty & Zavadskas)	2014	Utilised research	Applied WASPAS, MOORA and MULTIMOORA for robustness verification
(Dadelo, Turskis, Zavadskas, & Dadeliene)	2012	Utilised research	Personnel selection and evaluation by applying ARAS
(Dėjus & Antuchevičienė)	2013	Utilised research	Applied WASPAS and SWARA for regions evaluation for solar projects
(Džiugaitė-Tumėnienė & Lapinskienė)	2014	Utilised research	Analysis of performance by applying WASPAS for journals of Civil engineering
(Šiožinytė & Antuchevičienė)	2013	Utilised research	Used WASPAS COPRAS; AHP and TOPSIS for problem solving of tradition continuity and daylighting
(Zavadskas, Turskis, & Vilutiene)	2010	Utilised research	Used ARAS for foundation instalment selection
(Zavadskas & Vilutienė)	2006	Utilised research	Selection and evaluation of performance in maintenance contractor's by used COPRAS
(Hashemkhani Zolfani Esfahani, Bitarafan, Zavadskas, & Arefi)	2013	Utilised research	Applied SWARA and WASPAS for selection of shopping mall location
(Zavadskas, Kaklauskas, & Vilutiene)	2009	Utilised research	Dwelling maintenance contractors' evaluation by using COPRAS
(Zavadskas, Kaklauskas, Banaitis, & Kvederyte)	2004	Utilised research	Implemented of COPRAS for rational credit development and choosing the best efficient housing investment instruments and lenders
(Zavadskas, Kaklauskas, Turskis, & Tamošaitiene)	2008	Utilised research	Implemented COPRAS and COPRAS-G for selection of effective dwelling house walls
(Zavadskas, Kaklauskas, Turskis, Tamosaitiene, & Kalibatas)	2011	Utilised research	Used COPRAS-G for assessment of indoor environment
(Zavadskas, Turskis, Volvačiovas, & Kildiene)	2013	Utilised research	Technology selection by applied MULTIMOORA, SWARA-TOPSIS, SAWARA-VIKOR, SAWARA-ELECTURE III in construction sector

(*Continued*)

Table 9. (*Continued*).

Authors	Year	Type of study	Tools and approaches
(Zavadskas, Turskis, Tamošaitiene, & Marina)	2008	Utilised research	Used COPRAS-G for selection of constructions' projects managers
(Liu, Fan, Li, & Chen)	2014	Utilised research	Developed FMEA model by implemented of Extended MULTIMOORA
(Liu, You, Lu, & Shan)	2014	Utilised research	Selection and evaluation of technology in health-care waste treatment by using interval 2-tuple linguistic MULTIMOORA
(Aghdaie, Hashemkhani Zolfani, & Zavadskas)	2014	Utilised research	Used SWARA-VIKOR for selection of personnel
(Hashemkhani Zolfani & Bahrami)	2014	Utilised research	Ranking high tech industries by employed SWARA-COPRAS
(Jana, Bairagi, Paul, Sarkar, & Saha)	2013	Utilised research	Scheduling priority in manufacturing system by used MOORA
(Kaklauskas, Zavadskas, Raslanas, Ginevicius, Komka, & Malinauskas)	2006	Utilised research	Employed COPRAS for low- e windows selection in public buildings
(Kaklauskas, Zavadskas, Naimavicienė, Krutinis, Plakys, & Venskus)	2010	Utilised research	Applied COPRAS for intelligent built environment to improve inhabitant's quality of life and to satisfy inhabitants
(Kalibatas, Zavadskas, & Kalibatienė)	2012	Utilised research	Applied MAAIA and MOORA for selection of apartment with optimal indoor
(Kanapeckiene, Kaklauskas, Zavadskas, & Seniut)	2010	Utilised research	Used COPRAS for new original Knowledge Based Decision Support System in Construction Projects Management
(Karande & Chakraborty)	2012	Utilised research	Selection of ERP system by using fuzzy MOORA
(Keršuliene, Zavadskas, & Turskis)	2010	Utilised research	SWARA and WASPAS for regions evaluation for solar projects
(Kracka & Zavadskas)	2013	Utilised research	Selection of MOORA and MULTIMOORA for panel building
(Kracka, Brauers, & Zavadskas)	2010	Utilised research	Applied MOORA and MULTIMOORA for heating losses ranking in building
Keršulienė and Turskis	2011	Utilised research	Used ARAS-F and SWARA for selection of architect
(Ruzgys, Volvačiovas, Ignatavičius, & Turskis)	2014	Utilised research	SWARA, COPRAS, SAW and TOPSIS for strategy of public buildings retrofit
(Stankevičienė, Sviderskė, & Miečinskienė)	2014	Utilised research	Assessment of country risk sustainability by using MULTIMOORA and MOORA
(Baležentis, Baležentis, & Brauers)	2011	Utilised research	Well–being optimisation by applying MULTIMOORA
(Vafaeipour, Hashemkhani Zolfani, Morshed Varzandeh, Derakhti, & Keshavarz Eshkalag)	2014	Utilised research	Wind turbine selection by employed WASPAS

(*Continued*)

Table 9. (*Continued*).

Authors	Year	Type of study	Tools and approaches
(Brauers & Zavadskas)	2006	Utilised research	Proposed MOORA for transition of economy
(Brauers & Ginevičius)	2009	Utilised research	Applied MOORA for robustness in different regions of Lithuania
(Brauers)	2013	Utilised research	Used MOORA for selection of the best location of seaport
((Brauers, Kildienė, Zavadskas, & Kaklauskas)	2013	Utilised research	Assessment of construction sector based on macroeconomic view by using MULTIMOORA
(Brauers, Kracka, & Zavadskas)	2012	Utilised research	Building elements selection by using MULTIMOORA and MOORA
(Brauers, Zavadskas, Peldschus, & Turskis)	2008	Utilised research	Applied MOORA for evaluation of road design
(Brauers, Zavadskas, Turskis, & Vilutiene)	2008	Utilised research	Applied MOORA for best performing contractor
(Hashemkhani Zolfani & Saparauskas)	2013	Utilised research	Used SWARA for evaluation of energy system sustainability

Source: Authors' calculation.

Table 10. Distribution papers based on DEMATEL.

Authors	Year	Type of study	Tools and approaches
(Bai & Sarkis)	2013	Utilised research	Assessment of business process management by utilising DEMATEL
(Hsu, Kuo, Chen, & Hu)	2013	Utilised research	Selected of supplier by using DEMATEL for evaluation of carbon management
(Hu, Lee, Yen, & Tsai)	2009	Utilised research	Analysed performance in computer industry by using DEMATEL
(Ho, Feng, Lee, & Yen)	2012	Utilised research	Assessed performance of supplier quality by implementing DEMATEL
(Horng, Liu, Chou, & Tsai)	2013	Utilised research	Applied DEMATEL for assessment of criteria for design of restaurant space
(Lee & Lin)	2013	Utilised research	Used DEMATEL for the cognition maps of financial experts
(Li, Hu, Zhang, Deng, & Mahadevan)	2014	Utilised research	Ranking of CSFs of emergency management by using DEMATEL

Source: Authors' calculation.

4.10. Distribution based on MCDM techniques and approaches

Tables 3–11 show implementation of each MCDM technique and approach. Based on the results presented in these tables, a total of 393 studies have employed classical DM techniques and approaches, these Tables show that AHP with 128 articles has been used more than other tools and approaches. The second one is the other and integrated

Table 11. Distribution papers based on hybrid MCDM.

Authors	Year	Type of study	Tools and approaches
(Abdi & Labib)	2011	Utilised research	Applied ANP and AHP for RMS performance evaluation
(Cortés-Aldana, García-Melón, Fernández-de-Lucio, Aragonés-Beltrán, & Poveda-Bautista)	2009	Utilised research	Used AHP and ANP for evaluation of universities technology transfer
(Altuntas, Dereli, & Yilmaz)	2012	Utilised approach	Applied AHP and ANP for evaluation of SERVQUAL model in hospitals
(Ayağ & özdem r)	2007	Utilised research	Applied AHP and ANP for evaluation of customers and company based on the needs and expectations
(Bouyssou & Marchant)	2007	Developed research	Mixed ELECTRE TOPSIS, VIKOR and PROMETHEE for stability intervals and trade-offs analysis
(Büyüközkan & Öztürkcan)	2010	Utilised research	Combined DEMATEL, ANP for selection of Six Sigma project
(Liu, Tzeng, & Lee)	2012	Utilised research	Utilised DEMATEL, VIKOR and ANP for improvement of tourism policy
(Çalışkan)	2013	Utilised research	Used EXPROM2 VIKOR and TOPSIS and methods for selection of the best coating material
(Çalışkan, Kurşuncu, Kurbanoğlu, & Güven)	2013	Utilised research	PROMETHEE II, VIKOR and TOPSIS for the tool selection in hard milling
(Chatterjee & Chakraborty)	2012	Utilised research	Utilised PROMETHEE II and COPRAS-G for solving problem in selection of solving a gear material
(Chatterjee, Athawale, & Chakraborty)	2009	Utilised research	Employed VIKOR and ELECTRE for selection of suitable material in engineering application
(Chatterjee, Athawale, & Chakraborty)	2011	Utilised research	Combined COPRAS and EVAMIX for selection of suitable material in engineering application
(Chen, Lien, & Tzeng)	2010	Utilised research	Applied ANP and DEMATE for assessment of environment watershed plans
(Chen, Jin, Qiu, & Chen)	2014	Utilised research	Used AHP and Entropy for safety assessment
(Chen & Wu)	2010	Utilised research	Used AHP and ANP for evaluation of automobile manufacturer
(Chen & Tzeng)	2011	Utilised research	Integrated DEMATEL, VIKOR and ANP for evaluation of aspired intelligent
(Chin, Xu, Yang, & Ping-Kit Lam)	2008	Utilised research	Mix AHP and ER for screening of product project.
(Chu, Shyu, Tzeng, & Khosla)	2007	Utilised research	Utilised VIKOR, TOPSIS and SAW for assessment of Knowledge management
(Corrente, Greco, & Słowiński)	2013	Developed research	Extended PROMETHEE and ELECTRE for the hierarchy of criteria

(*Continued*)

Table 11. (*Continued*).

Authors	Year	Type of study	Tools and approaches
(Corrente, Greco, & Słowiński)	2012	Developed research	Proposed MCHP for handles of hierarchy criteria in MCDA
(Dembczyński, Greco, & Słowiński)	2009	Developed research	Extended DRSA for solving problems in multiple criteria classification
(Ergu, Kou, Peng, & Shi)	2011	Developed research	Combined ANP and AHP for identify the inconsistent elements in the pair-wise comparison matrix
(Greco, Matarazzo, & Słowiński)	2013	Proposed research	Proposed DRSA for solving multi-objective optimisation problems
(Goh, Kok, Yeo, Lee, & Mohd. Zin)	2013	Utilised research	Used AHP and TOPSIS for assessment of large pulp mill electrical system
(Haldar, Ray, Banerjee, & Ghosh)	2012	Utilised research	Employed TOPSIS and AHP for selection and evaluation of suppliers
(Huang, Chang, Li, & Lin)	2013	Developed research	Used MAUT and SAW for GDM problems
(J. J. Liou)	2012	Utilised research	Mixed DEMATEL and ANP for selection of airlines suitable partners for strategic alliances
(Jalao, Wu, & Shunk)	2014	Developed research	Proposed PCM for applied in AHP and ANP
(Jeng & Bailey)	2012	Utilised research	Integrated DEMATEL and ANP for evaluation of customer retention framework and promotional strategies
(Kadziński, Greco, & Słowiński)	2012b	Proposed research	Proposed ELECTRE^{GKMS} and PROMETHEE^{GKS} based on robust ordinal regression
(Kasanen, Wallenius, Wallenius, & Zionts)	2000	Utilised research	Employed MCDM/MAUT for evaluating the managerial decision process
(Kasirian & Yusuff)	2013	Utilised research	Utilised TOPSIS and AHP for supplier selection
(Khorshidi & Hassani)	2013	Utilised research	Applied AHP and TOPSIS for selection of PSI materials
(Kuo, Yang, Cho, & Tseng)	2008	Utilised research	Applied TOPSIS and AHP for selection of suitable dispatching rule for workstation
(Lee & Tu)	2011	Utilised research	Combined DEMATEL, ANP and VIKOR for evaluation of company value
(Leung & Cao)	2001	Developed research	Used ANP, Sinarchy and AHP for problems solving in MADM problems
(Lin, Wang, Chen, & Chang)	2008	Utilised research	Identified customer requirements and design characteristics by used AHP and TOPSIS
(Macharis, Springael, De Brucker, & Verbeke)	2004	Developed research	PROMETHE and AHP for synergies of operational design

(*Continued*)

Table 11. (*Continued*).

Authors	Year	Type of study	Tools and approaches
(Makan, Malamis, Assobhei, Loizidou, & Mountadar)	2012	Utilised research	Applied PROMETHEE and AHP for selection of suitable site for a new landfill
(Mousavi, Tavakkoli-Moghaddam, Heydar, & Ebrahimnejad)	2013	Utilised research	PROMETHEE, Delphi and AHP for selection of plant location
(Nakagawa, Nasu, Saito, & Yamaguchi)	2010	Developed research	Proposed research based on AHP and ANP for evaluation of policy alternative
(Opricovic & Tzeng)	2004	Developed research	TOPSIS and VIKOR for aggregating function and normalisation problems
(Oztaysi)	2014	Utilised research	Used TOPSIS and AHP for selection of information technology
(Partovi & Corredoira)	2002	Utilised research	Employed AHP and ANP for evaluation of QFD
(Peng)	2012	Utilised research	Combined TOPSIS, PROMETHEE II, VIKOR, ELECTRE III, GRA, and WSM for evaluation of the earthquake vulnerability
(Peng, Wang, & Wang)	2012	Utilised research	ELECTRE I, DEA, PROMETHEE II and TOPSIS for evaluation and ranking a selection of classification algorithms
(Percin)	2009	Utilised research	Used AHP and ANP For selection of 3PL providers' criteria
(Raju, Duckstein, & Arondel)	2000	Utilised research	Used ELECTRE III, PROMETHEE II, EXPROM II, ELECTRE VI and CP for assessment of economic factors
(Hu, Lu, & Tzeng)	2014	Utilised research	Employed DEMATEL, DANP and VIKOR for improvements of smart phone
(Sarkis & Sundarraj)	2002	Utilised research	Combined AHP and ANP for Hub location evaluation and selection
(Shyjith, Ilangkumaran, & Kumanan)	2008	Utilised research	Mixed AHP and TOPSIS for maintenance policy selection
(Shyur)	2006	Utilised research	Evaluated overall performance by employing ANP and TOPSIS
(Singh & Kumar)	2013	Utilised research	Utilised AHP and TOPSIS for assessment of technologies in effective utilisation of advanced manufacturing
(Streimikiene, Balezentis, Krisciukaitienė, & Balezentis)	2012	Utilised research	Employed TOPSIS and MULTIMOORA for selection of sustainable energy sources
(Yang, Chen, & Hung)	2007	Utilised research	Used TOPSIS and AHP solve problem in dynamic operator allocation
(Tao, Chen, Liu, & Wang)	2012	Proposed research	Integrated DEA, AHP and TOPSIS for solving problems in MCDM
(Tsai, Lin, Lee, Chang, & Hsu)	2013	Utilised research	Used DEMATEL and ANP for evaluation of green building project

(*Continued*)

Table 11. (*Continued*).

Authors	Year	Type of study	Tools and approaches
(Tzeng & Huang)	2012	Utilised research	Applied VIKOR, DEMATEL and GRA for selection of global manufacturing and logistics strategy
(Wu)	2008	Utilised research	Integrated DEMATEL and ANP for evaluation of knowledge management system
(Wu, Lin, & Tsai)	2010	Utilised research	Applied AHP and GRA for evaluation of business performance wealth management banks
(Wang & Triantaphyllou)	2008	Developed research	Applied ELECTRE II and ELECTRE III for solving MCDM problems
(Xu)	2001	Developed research	Employed SAW, TOPSIS and PROMETHEE for ranking superiority and inferiority
(Yurdakul)	2004	Utilised research	Used AHP and ANP for assessing machine tool alternatives to the manufacturing strategy

Source: Authors' calculation.

articles of hybrid MCDM tools and approaches and DM aggregation methods are the third in this ranking.

4.11. Distribution based on name of journal

Table 12 provides the distribution based on name of the journal which has been used in this survey. The article related to the MCDM techniques and approaches which are distributed through 120 journals and cover an extensive range of Web of Science database. From these 120 journals, the ranked first was the *European Journal of Operational*

Table 12. Distribution papers based on name of journal.

No.	Name of journal	Number of paper	No.	Name of journal	Number of paper
1	*European Journal of Operational Research*	70	61	*Journal of Engineering Design*	1
2	*Expert Systems with Applications*	20	62	*Journal of Intelligent Manufacturing*	1
3	*Applied Mathematical Modelling*	13	63	*International Journal of Production Economics*	1
4	*Materials & Design*	13	64	*Ecological Economics*	1
5	*Journal of civil engineering and management*	12	65	*Fuzzy sets and systems*	1
6	*Technological and Economic Development of Economy*	9	66	*Control and Cybernetics*	1
7	*Applied Mathematics and Computation*	9	67	*Journal of Purchasing and Supply Management*	1

(*Continued*)

Table 12. (*Continued*).

No.	Name of journal	Number of paper	No.	Name of journal	Number of paper
8	*Renewable Energy*	9	68	*International Transactions in Operational Research*	1
9	*International Journal of Production Research*	8	69	*Informatica*	1
10	*Transport*	8	70	*Asia Pacific Journal of Tourism Research*	1
11	*Knowledge-Based Systems*	8	71	*Journal of Decision Systems*	1
12	*Omega*	7	72	*Computers & Mathematics with Applications*	1
13	*Waste Management*	7	73	*Journal of Hydrology*	1
14	*Computers & Geosciences*	6	74	*Journal of economic computation and economic cybernetics studies and research*	1
15	*Journal of Materials Processing Technology*	6	75	*Fusion Engineering and Design*	1
16	*Computers & Industrial Engineering*	6	76	*Engineering Structures and Technologies*	1
17	*Journal of Business Research*	5	77	*The Egyptian Journal of Remote Sensing and Space Science*	1
18	*Energy Policy*	5	78	*Journal of Natural Fibers*	1
19	*Applied Soft Computing*	5	79	*Decision Support Systems*	1
20	*Computers & Operations Research*	4	80	*International Journal of Electrical Power & Energy Systems*	1
21	*International Journal of Project Management*	4	81	*Ocean & Coastal Management*	1
22	*Engineering Economics*	4	82	*Ecotoxicology and Environmental Safety*	1
23	*Journal of Business Economics and Management*	4	83	*International Journal of Hospitality Management*	1
24	*International Journal of Strategic Property Management*	4	84	*Asia Pacific Journal of Marketing and Logistics*	1
25	*Renewable and Sustainable Energy Reviews*	4	85	*Transportation Research Part E: Logistics and Transportation Review*	1
26	*International Journal of Management Science and Engineering Management*	4	86	*Neurocomputing*	1
27	*Transport Policy*	4	87	*Robotics and Computer-Integrated Manufacturing*	1
28	*Automation in Construction*	4	88	*Management Decision*	1
29	*Journal of Multi-Criteria Decision Analysis*	3	89	*Systems Engineering - Theory & Practice*	1
30	*Annals of Operations Research*	3	90	*Decision Science Letters*	1
31	*Journal of Environmental Management*	3	91	*Journal of the Chinese Institute of Industrial Engineers*	1
32	*Desalination*	3	92	*Applied Intelligence*	1
33	*Benchmarking: An International Journal*	3	93	*Journal of Air Transport Management*	1

(*Continued*)

Table 12. (*Continued*).

No.	Name of journal	Number of paper	No.	Name of journal	Number of paper
34	*Economic Modelling*	2	94	*Journal of China University of Mining and Technology*	1
35	*International Journal of Mining Science and Technology*	2	95	*journal of production engineering*	1
36	*Journal of Manufacturing Systems*	2	96	*Ships and Offshore Structures*	1
37	*Land Use Policy*	2	97	*Forest Policy and Economics*	1
38	*Journal of Information and Optimization Sciences*	2	98	*Arabian Journal for Science and Engineering*	1
39	*Environmental Modelling & Software*	2	99	*Electric Power Systems Research*	1
40	*Energy*	2	100	*Telecommunications Policy*	1
41	*Journal of Manufacturing Technology Management*	2	101	*International Journal of Energy Sector Management*	1
42	*Energy Conversion and Management*	2	102	*International Journal of Disaster Risk Reduction*	1
43	*Applied Energy*	2	103	*Computer Aided Chemical Engineering*	1
44	*Tourism Management,*	2	104	*Process Safety and Environmental Protection*	1
45	*Journal of Cleaner Production*	2	105	*Water Resources Management*	1
46	*Information sciences*	2	106	*Supply Chain Management: An International Journal*	1
47	*Kybernetes*	2	107	*Construction and Building Materials*	1
48	*Energy and Buildings*	2	108	*Applied Geography*	1
49	*Food Quality and Preference*	2	109	*Nuclear Engineering and Design*	1
50	*Engineering Applications of Artificial Intelligence*	2	110	*Mining Science and Technology*	1
51	*Mathematics and Computers in Simulation*	2	111	*Structural Survey*	1
52	*Maritime Policy & Management*	2	112	*Resources Policy*	1
53	*Computers in Industry*	2	113	*Evaluation and Program Planning*	1
54	*International journal of hydrogen energy*	2	114	*Journal of Environmental Planning and Management*	1
55	*Journal of Quality in Maintenance Engineering*	2	115	*Journal of Quality Assurance in Hospitality & Tourism*	1
56	*CATENA*	2	116	*Tunnelling and Underground Space Technology*	1
57	*Archives of Civil and Mechanical Engineering*	2	117	*Asia Pacific Management Review*	1
58	*Resources, Conservation and Recycling*	1	118	*Computer Modelling and New Technologies*	1
59	*Total Quality Management & Business Excellence*	1	119	*Studies in Informatics and Control*	1
60	*Journal of Safety Research*	1	120	*Journal of Computational Science*	1

Source: Authors' calculation.

Research with 70 articles. According to this result we can indicated that this journal has the most significant role in MCDM issues. The *Journal of Expert Systems with Applications* and *Applied Mathematical Modelling* had the second and third rank with 20 and 13 articles respectively, although the *Journal of Materials & Design* with 13 articles also had third rank. In other journal ranking; the *Journal of Civil Engineering and Management* had the fourth rank with 12 articles, moreover; the *Journal of Applied Mathematics and Computation*, *Journal of Technological and Economic Development of Economy* and *Journal of Renewable Energy* had the fifth rank with nine articles. The total number of publications of other published journals is shown in Table 12.

4.12. Distribution based on publication year

Figure 1 presents important evidence based on the frequency of distribution by the year of publication. The results indicate that from 2000 to 2014, the information about the use of DM techniques and approaches have grown increasingly. According to the findings of this section, the use of these techniques and approaches in 2000 was three articles and this number increased to 10 articles in 2001. Surprisingly, from 2006 to 2007, the numbers of studies dramatically increased. Although the use of MCDM techniques and approaches has increased in each year, the numbers of those articles in 2005 have decreased compared to 2004. Another interesting result in this is about 2013, in which previous studies have applied techniques more than other years. This year has the highest number of publications (75). Accordingly, it can be indicated that researchers in different fields and categories use the MCDM techniques and approaches nowadays in their research, and it can be predicted that in coming years, these numbers will increase. Results of the publication years is shown in Figure 1.

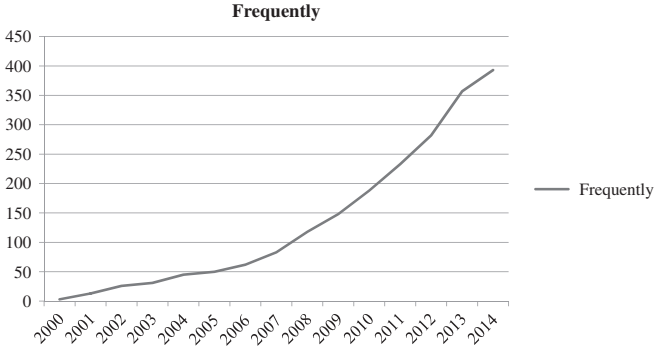

Figure 1. Distribution papers based on the total number of publications.
Source: Authors' calculation

5. Discussion

This study attempted to review articles published over 15 years (2000–2014) about MCDM techniques and approaches in 120 international peer-reviewed journals, which are accessible via the database system Web of Science. The first aim of this article was to systematically review the studies conducted based on MCDM techniques and approaches.

To this end a total of 393 published articles about MCDM were systematically and carefully chosen and summarised based on title, abstract, introduction, research method, and conclusion. Then, according to the predefined objective of this study, those articles related to MCDM techniques and approaches were selected. In this review, the obtained results were analysed based on six research questions; these questions were: (1) which DM techniques have been used?; (2) Which type of study has been conducted on these MCDM techniques?; (3) Which one of the 15 fields has further used these MCDM techniques?; (4) What kinds of MCDM tools have been employed in these years based on 15 fields?; (5) Which journals published articles related to these MCDM methods and approaches?; and (6) In which one of the years have authors published further articles related to MCDM methods and approaches based in the 15 fields? To answer the first question, we considered the results presented in Table 2 that showed the number and percentage of those MCDM techniques and approaches. This table revealed that the AHP technique with 128 studies was ranked as the first among other techniques and approaches; additionally, hybrid MCDM techniques and approaches were ranked second with 58 articles. The second question was which type of study has been conducted on these MCDM techniques? To answer the second question, we read the methodology section of each article very carefully and classified the studies in three types. Based on our reading, some studies have used MCDM techniques and approaches for solve DM problems. Based on our experience and discussions held with some experts on DM issues about this type of studies, we decided to call this type of study MCDM utilising research. Some scholars have attempted to develop DM techniques and approaches based on their objectives; therefore, the MCDM developing research is considered as the second type of study. Furthermore; our review indicated that some researchers have proposed new approach based on DM techniques and approaches, which we named MCDM proposing research type. The answers to questions three and four were presented section Table 1 and Table 2. These tables indicated that from 393 articles, operation research and soft computing area had the first rank with 109 studies (27.74%), most of the articles in this area attempted to develop and improve DM techniques and approaches for solving problems in MCDM issues. From 15 application areas, the second rank was energy, environmental and sustainability fields with 53 articles (13.49%). We believed that in recent years, most of scholars in fields of energy, environment and sustainability have applied MCDM and MCDM techniques and approaches and techniques for solving problems in these areas. In addition; based on results in Table 2, we found that previous studies have used the AHP technique more than other techniques and approaches in these 15 applications areas, also, hybrid MCDM techniques and approaches was ranked second with 64 articles (16.28%). Moreover, TOPSIS and aggregation DM methods had the third and fourth rank with 45 (11.66%) and 46 (11.92%) articles respectively. Furthermore, based on the findings in Table 2, ANP (7.38%), PROMETHEE (6.62%), ELECTRE (8.65%), DEMATEL (1.78%) and VIKOR (3.56%) had next subsequent ranks.

Question five was: (5) which journal published articles related to these MCDM methods and approaches? Table 12 showed the results of this question, as we can see in this table, from 120 journals; ranked first was the *European Journal of Operational Research* with 70 articles. According to this result, we can indicate that the *Journal of Expert Systems* and *Applications and Applied Mathematical Modelling* had the second and third rank with 20 and 13 articles respectively, although the *Journal of Materials & Design* with 13 articles was ranked third. In other journal ranking the *Journal of Civil Engineering and Management* was ranked fourth with 12 articles. Moreover the *Journal of Applied Mathematics and Computation*, the *Journal of Technological and Economic*

Development of Economy and the *Journal of Renewable Energy* was ranked fifth with nine publications. The total number of publications of other published journals shows in Table 12. Question six was: (6) in which year have authors published further articles relating to MCDM methods and approaches based in the 15 fields? Figure 1 presents important evidence based on the frequency of distribution by the year of publication. The results indicate that from 2000 to 2014, the information about the use of DM techniques and approaches have grown. According to the findings of this section, the use of these techniques and approaches in 2000 was three articles and this number increased to 10 articles in 2001.

6. Conclusion

In DM applications and theories, different modelling techniques have been offered, a number of suitable approaches have been provided for modelling decision aiding and help is provided for the development of alternatives as they consider the complexity of the process. Choosing a problem solution approach and a model is dependent upon the actors that are involved in the process of DM, desired goals, available information, time, and so on. The most important advantage of the multiple criteria methods is their capability of addressing the problems that are marked by different conflicting interests. Using these techniques, actors are capable of solving the problems that it is not possible to solve by the use of common optimisation models. MCDM techniques and approaches are being employed increasingly for the evaluation of alternatives and comparative analysis. Moreover, a number of significant concepts are discussed, which have not been addressed in previous studies. We provide a systematic review of MCDM which classifies articles in 15 difference areas including; energy, environment and sustainability, supply chain management, material, quality management, GIS, construction and project management, safety and risk management, manufacturing systems, technology management, operation research and soft computing, strategic management, knowledge management, production management, tourism management and other fields. Several significant articles about MCDM issues are introduced in this article.

We have reviewed the literature for the classification and interpretation of the emerging issues that make use of the MCDM methodology. In the present review, a total of 393 scholarly articles were collected from 120 journals, published since 2000, and they were categorised into 15 areas. The articles were classified based on the journal's name, publication year, application areas, and several MCDM techniques and approaches including; AHP, TOPSIS, ELECTRE, hybrid MCDM, ANP, PROMETHEE, DEMATEL DM aggregation methods (ARAS, WASPAS, SWARA, MOORA, MULTIMOORA and COPRAS) and VIKOR. This article contributes to the development of a classification scheme focusing on practical considerations, structurally reviewing the literature to create a guide for further studies on MCDM techniques and approaches, and the identification of issues for future studies. Additionally, in our study, two new perspectives are taken into consideration when reviewing the articles, namely categorisation of the articles in 15 areas and examination of the type of study (MCDM utilising research, MCDM developing research and MCDM proposing research).

Generally, the MCDM methodology has been used successfully in various applications and industrial sectors with different subjects and terms, although interdisciplinary and social decision problems should be further emphasised. Future study on the MCDM anatomy can be developed. In this study, a number of techniques have been studied as individual techniques and they are integrated or combined with other techniques;

however, some conventional MCDM techniques and approaches have not been studied. Another recommendation for future research is the investigation on the distinct differences and similarities among MCDM techniques and approaches. The insights that are provided in this article help channel research efforts and fulfil practitioners' and researchers' requirements for an easy reference to MCDM publications and studies.

This study has some major limitations that can be considered as recommendations for future studies. First, this review is focused on the use of DM techniques. Articles published in late 2014, if any, are not included in the present article due to the limited reporting time. A future review can be expanded further in scope. In addition, our article focuses on 15 fields. In this regard, future studies can use this article for classify based on different sub-fields and sub-areas. Another limitation is that the data were collected from journals, not including articles conference articles, textbooks, doctoral and master dissertations, PhD thesis and unpublished articles in the MCDM issues. Therefore, in future studies, data can be collected from these scholarly journals and the obtained results can be compared with our results. The next limitation is that the all of articles were found in English language journals, scholarly journals in the other languages were not involved in our review article. It may mean that this article is incomplete; however, we believe that we comprehensively review and include most of the articles presented by 120 high-ranking journals. As a result, our review article can provide a better understanding of MCDM techniques and approaches for future academic scholars. We hope this study will be employed by academics and managers as a basis for further research and will help practitioners make more appropriate decisions using these techniques, and guide scholars to enhance these methodologies. This article selected and summarised carefully those articles that were available from publishers in Web of Science, although, a number of relevant outlets may have remained outside the scope of this study. Therefore, future studies can review those articles which we did not discuss in this review article.

Recently, the development of hybrid and modular methods is becoming increasingly important. They are based on previously developed well-known methods, such as TOPSIS, SAW, DEA, AHP, ANP, VIKOR, DEMATEL, DEA, PROMETHEE, ELECTRE and their modification, by applying fuzzy and grey number theory. Relatively recently developed MCDM methods, such as COPRAS, ARAS-F, MOORA, MULTIMOORA, SWARA and WASPAS are rapidly developed and applied to solve real life problems. In order to help researchers and practitioners interested in hybrid MCDM techniques and approaches, it is necessary to publish reviews on these issues in future. This article presents synopses of numerous publications, which describe the use of MCDM methods in journals and some of the relatively recently developed methods. However, this review does not cover recent methods which have not yet been reviewed in books.

Disclosure statement

No potential conflict of interest was reported by the authors.

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