Expert Systems with Applications 42 (2015) 4126–4148

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Review

Fuzzy multiple criteria decision-making techniques and applications – Two decades review from 1994 to 2014

Abbas Mardani [a,*], Ahmad Jusoh [a], Edmundas Kazimieras Zavadskas [b]

[a] Department of Management, Faculty of Management, Universiti Teknologi Malaysia (UTM), Skudai, Johor 81300, Malaysia
[b] Department of Construction Technology and Management, Vilnius Gediminas Technical University, Sauletekio al. 11, LT-10223 Vilnius, Lithuania

ARTICLE INFO

Article history:
Available online 10 January 2015

Keywords:
Fuzzy multiple criteria decision making
Multiple criteria decision making
Literature review

ABSTRACT

MCDM is considered as a complex decision-making tool involving both quantitative and qualitative factors. In recent years, several fuzzy FMCDM tools have been suggested to choosing the optimal probably options. The purpose of this paper is to review systematically the applications and methodologies of the fuzzy multi decision-making (FMCDM) techniques. This study reviewed a total of 403 papers published from 1994 to 2014 in more than 150 peer reviewed journals (extracted from online databases such as ScienceDirect, Springer, Emerald, Wiley, ProQuest, and Taylor & Francis). According to experts' opinions, these papers were grouped into four main fields: engineering, management and business, science, and technology. Furthermore, these papers were categorized based on authors, publication date, country of origin, methods, tools, and type of research (FMCDM utilizing research, FMCDM developing research, and FMCDM proposing research). The results of this study indicated that, in 2013, scholars have published papers more than other years. In addition, hybrid fuzzy MCDM in the integrated method and fuzzy AHP in the individual section were ranked as the first and second methods in use. Additionally, Taiwan was ranked as the first country that contributed to this survey, and engineering was ranked as the first field that has applied fuzzy DM tools and techniques.

1. Introduction

Multiple-criteria decision making (MCDM) has grown as a part of operations research, concerning with designing computational and mathematical tools for supporting the subjective evaluation of performance criteria by decision makers (Banaitiene, Banaitis, Kaklauskas, & Zavadskas, 2008; Behzadian, Khanmohammadi Otaghsara, Yazdani, & Ignatius, 2012; Zavadskas, Skibniewski, & Antucheviciene, 2014). Several studies have been carried out to develop MCDM (Dadelo, Turskis, Zavadskas, & Dadeliene, 2014; Shyur & Shih, 2006; Yazdani-Chamzini, Shariati, Haji Yakhchali, & Zavadskas, 2014). In recent years several previous studies have employed MCDM tools and applications for solve areas problems such as engineering (Zavadskas, Antucheviciene, Hajiagha, & Hashemi, 2014), science (Zavadskas et al., 2014), technology (Bagočius, Zavadskas, & Turskis, 2014; Dadelo et al., 2014; Streimikiene, Balezentis, Krisciukaitienė, & Balezentis, 2012). In real world, problems in regard to decision making are generally uncertain in a number of ways. Lack of information can lead to an unclear future state of the system. This uncertainty has been addressed using the probability theory and statistics. Though, in various situations of daily life; for evaluation, judgment, and decision, natural language is often employed in order to articulate thinking and subjective perceptions. In these natural languages, words might not have a clear and well-defined meaning. As a result, if the word is used as a label for a set, the boundaries of the set to which objects do or do not belong will become fuzzy. In addition, when individuals are judging an event, even using the same words, they may significantly differ since each of them has different subjective perception or personality.

To overcome this problem, fuzzy numbers are introduced in a way to help linguistic variables be expressed appropriately. Due to the fact that investors often evaluate investment strategies based on their own subjective preferences in terms of numerical values from different criteria, it is better to regard this situation as a Fuzzy Multiple Criteria Decision-Making (FMCDM) problem.

The present study has the following contributions: Fuzzy FMCDM is one of the most widely used decision methodologies in engineering, technology, science and management and business. FMCDM approaches improve the quality of decisions by creating

* Corresponding author. Department of Management, Faculty of Management, Universiti Teknologi Malaysia (UTM), Skudai, Johor, Malaysia. Tel.: +60 1127347432.
E-mail addresses: mabbas3@live.utm.my (A. Mardani), ahmadj@management.utm.my (A. Jusoh), Edmundas.Zavadskas@vgtu.lt (E.K. Zavadskas).

http://dx.doi.org/10.1016/j.eswa.2015.01.003
0957-4174/

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 the 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 decade, the FMCDM methods have received a great deal of attention from practitioners and researchers. This paper attempts to document the exponentially grown interest in the FMCDM methods and provide a state-of the-art review of the literature regarding the FMCDM applications and methodologies. Based on a classification scheme, a reference repository has been established, including 403 papers published in more than 150 international journals from 1994. Papers are classified based on the year of publication, application areas, authors' nationality of authors, and FMCDM approaches combined with other methods. This paper is evolving a categorizing structure with focusing on applicable considerations, presenting an organized review in a way to provide a guide to previous studies on the FMCDM methods, and recognizing topics for future research. Additionally, in our study, two new perspectives are taken into consideration to review the articles, namely categorization of the articles into four main fields (business, science, engineering, and technology) and examination of the type of study (FMCDM utilizing research, FMCDM developing research, FMCDM proposing research).

In this paper, the literature related to the descriptors of FMCDM has been reviewed comprehensively using academic databases of Springer, ScienceDirect, Emerald, Wiley, ProQuest, and Taylor & Francis. Following a methodological decision analysis on the whole collected articles, a total of 403 international journal articles published from 1994 to 2014 were reviewed. The present paper attempts to answer the following questions: (1) which fuzzy decision-making (DM) techniques have been used frequently? (2) Which type of study has been conducted on these FMCDM techniques? (3) Which one of the four fields (science, business, technology, and engineering) has further used these FMCDM techniques? (4) What kinds of FMCDM tools have been employed in these years based on four main fields? (5) Which countries have published articles related to these FMCDM tools based on the number of publishing in these four main fields? (6) In which one of the years authors have further published articles related to FMCDM tools based in the four fields?

The remainder of this paper is organized as follows. Section 2 provides a brief overview on literature review and framework. Section 3 describes the research methodology and the procedure of this study. Section 4 provides 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 conclusion, limitations, and recommendations for future studies.

2. Literature review on the fuzzy decision-making approaches

Over the years, numerous FMCDM methods have been proposed in the literature, which are different in areas such as the type of questions asked, theoretical background, and type of obtained results. A number of methods have been designed for a particular problem, hence inapplicable to other problems. Recently, a number of FMCDM methods have been introduced to choose the best compromise options. The FMCDM approaches have been developed not only by the motivation received from various real-life problems that require the consideration of multiple criteria, but also by the desire of practitioners for enhancing decision-making techniques through recent developments occurred in computer technology, scientific computing, and mathematical optimization (Wiecek, Ehrgott, Fadel, & Rui Figueira, 2008). All methods are mainly aimed to make the decision making process better-informed and more formalized. In a number of previous studies, MCDM and fuzzy MCDM have been classified into various fields and approaches (Baležentis, Valkauskas, & Baležentis, 2010; Chen, Hwang, Beckmann, & Krelle, 1992; Liou, 2013; Liou & Tzeng, 2012; Ölçer & Odabaşi, 2005; Ribeiro, 1996; Zavadskas & Turskis, 2011). The MCDM approach fall into two categories (Bashiri, Badri, & Hejazi, 2011; Pawlak, 1982; Wang & Lee, 2007; Wang & Lee, 2009; Xu & Da, 2002): classical MCDM and fuzzy FMCDM (Wang, Lee, & Lin, 2003). Fig. 1 presents the Fuzzy Multicriteria decision-making process. In the FMCDM approach, alternatives are ranked and selected from among a set of feasible alternatives.

The MCDM problems have different nature; thus, a variety of techniques have been proposed as the solution. The first proposed methods were complete aggregation ones. For example, SAW and two stages in weighting (MacCrimmon, 1968), MAUA (Keeney & Raiffa, 1976), WASPAS (Zavadskas, Turskis, Antucheviciene, & Zakarevicius, 2012), TOPSIS (C. Hwang & Yoon, 1981), VIKOR (Opricovic & Tzeng, 2004), COPRAS (Zavadskas, Kaklauskas, & Sarka, 1994), MOORA (Brauers & Zavadskas, 2006), COPRAS-G, ARAS-F, ARAS-G and MULTIMOORA (Brauers & Zavadskas, 2010; Turskis & Zavadskas, 2010b; Zavadskas & Turskis, 2008), ARAS (Turskis & Zavadskas, 2010a; Yager, 1994a). As examples of partial aggregation methods, PROMETHEE (Mareschal & Brans, 1992), ELECTRE (Roy, 1996), and NAIADE (Munda, 1998) can be listed, which involve the pair-wise comparisons of alternatives. In addition, the ANP and AHP are relied on the pair-wise comparisons (Saaty, 1988; Saaty, 2003; Saaty, 2005; Saaty & Vargas, 2006).

FMCDM can be categorized as a fuzzy multi objective decision-making (FMODM) and fuzzy multi attribute decision-making (FMADM) approach (Kadane, 2011; Liou & Tzeng, 2012; Ölçer & Odabaşi, 2005; Simões-Marques, Ribeiro, & Gameiro-Marques, 2000; Tzeng & Huang, 2011). Liou and Tzeng (2012), addressed

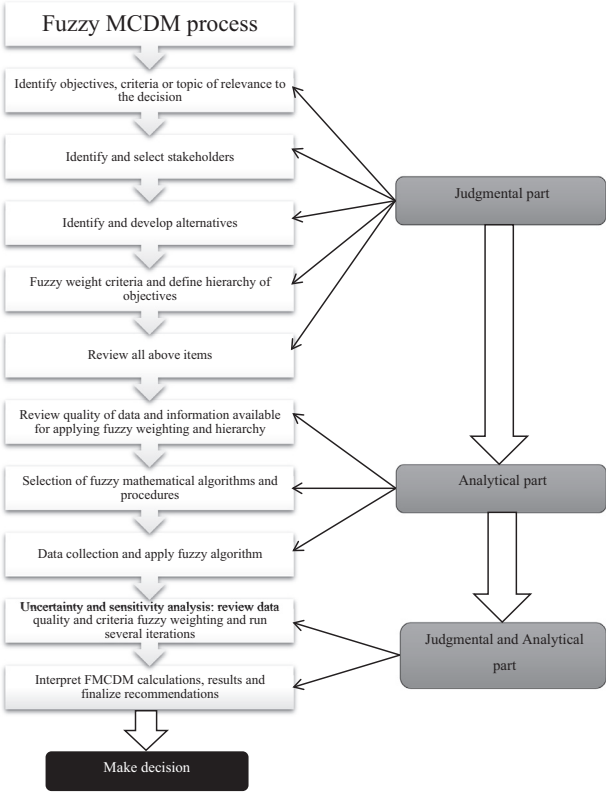

Fig. 1. Multicriteria decision process.

the development of MADM from 1738 to 2012. They put MADM into three classes: evaluating or choosing models (e.g., DEMATEL, fuzzy DEMATEL, ISM, fuzzy ISM, fuzzy cognitive map (FCM), linear structure equation models (LISEM, or called "SEM"), formal concept analysis, and input–output analysis), weighting models (ANP/fuzzy ANP, AHP/fuzzy AHP, entropy measure, neural network weighting, and dynamic weighting), and normalizing models (additive types: TOPSIS, SAW, VIKOR, ELECTRE, PROMETHEE, and gray relation and non-additive types: fuzzy integral neural network plus fuzzy). In another classification related to MCDM tools and approaches, Zavadskas and Turskis (2011) and Hwang and Yoon (1981) have grouped MCDM tools in different way, in two these studies, MCDM divided into three types information of actors including; no information (dominance, Maxmin and Minmax classes), information about criteria (standard level (conjunctive and Disjunctive), ordinal (lexicographic, elimination by aspects and permutation), cardinal (liner assignment, SAW, HSAW, TOPSIS, ELECTRE, PROMETHEUS, ORESTE, VIKOR, COPRAS, ARAS and MOORA) and marginal rate of substitution (hierarchical tradeoffs)) and information of alternative (pairwise preference (LINMAP and SAW) and order of pairwise proximity (multidimensional scaling)).

The objective of FMADM is finite and implicit, whereas the objective of the FMODM approach is infinite and explicit. In FMADM, the decision maker's objectives are unified under the decision-makers' utility that is a super function, which is dependent upon the selection criteria. In FMODM, objectives of the decision-makers, e.g., optimal resource utilization and quality improvement and remain explicit are assigned with fuzzy weights that reflect their relative significance. The most important benefit of FMCDM models is their capability of considering many selection criteria. Bellman and Zadeh (1970) and Zimmermann (1978) applied fuzzy sets to the MCDM field. According to Yager (1978), the fuzzy set of a decision is the intersection of the whole fuzzy goals. Kickert (1978), prepared a summary of applications of the fuzzy set theory to MADM problems.

Literature contains a number of classifications of MCDM tools with fuzzy theory sets. For instance, Peneva and Popchev (2008) stated that if the weights are given as real numbers, the operators such as Weighted Mean (Chiclana, Herrera, & Herrera-Viedma, 1998), Weighted MaxMin and Weighted MinMax (Fodor & Roubens, 1995), and Weighted Geometric (Chiclana, Herrera, & Herrera-Viedma, 2000) can be applied to the aggregation of fuzzy relations. In the mathematical model, there are operators in which the weights do not present the operators: Min, Max, MaxMin (Altrock, 1997), Gamma (Altrock, 1997), and Generalized Mean (da Costa Sousa & Kaymak, 2001). The idea of using the given weights in this case was suggested in (Yager, 1994b). The two other categories proposed by Hwang, Chen, and Hwang (1992) consist of some ways for finding a ranking, including the degree of optimality, linguistic ranking methods, comparison function, Hamming distance, proportion to the ideal, fuzzy mean and spread, centroid index, left and right scores, and area measurement. The second category contains methods that employ different ways for assessing the relative significance of multiple attributes, including analytic hierarchy process, fuzzy simple additive weighting methods, fuzzy outranking methods, fuzzy conjunctive/disjunctive methods, and maximin methods. Inuiguchi, Ichihashi, and Tanaka (1990), carried out a survey on recent developments occurred in fuzzy programming. In this work, they employed applications such as flexible programming, possibilistic programming, possibilistic linear programming with fuzzy goals, possibilistic programming with fuzzy preference relations, possibilistic linear programming using fuzzy max, and robust programming.

Based on the relationship among aggregated arguments, the aggregation operators can be divided roughly into two classes: those operators that consider the aggregated arguments dependently and those that consider the aggregated arguments independently. In case of the first class, Yager (1986) introduced the ordered weighted averaging (OWA) operator for reordering the arguments prior to being aggregated. This operator motivated Chiclana et al. (2000) and Xu and Da (2002) to propose the ordered weighted geometric (OWG) operator. Yager (2004), used the continuous interval-valued arguments to develop the continuous ordered weighted averaging (C-OWA) operator. Torra (2010) and Torra and Narukawa (2009) developed the hesitant fuzzy sets (HFSs) concept to present the hesitant fuzzy information, which covers the arguments with a set of possible values. This is considered as a new efficient tool for collecting and representing the arguments under uncertainty, particularly in the decision making process. Zhu, Xu, and Xia (2012), investigated the geometric BMs combined with hesitant fuzzy information and introduced the hesitant fuzzy geometric BMs (HFGBM). Yu, Wu, and Zhou (2012), developed the generalized hesitant fuzzy BM (GHFBM) with its application in the multicriteria group decision making.

The aggregation techniques have a great effect on the MCDM problems, and the aggregation operators have been broadly applied to MCDM. In a fuzzy environment, Chen and Tan (1994) developed a number of functions for measuring the extent to which each alternative is suitable regarding a set of criteria in MCDM. Hong and Choi (2000), used the maximum and minimum operations for the development of some approximate techniques of addressing the MCDM problems. In addition, the aggregation operators have been extended to intuitionistic fuzzy environment wherein IFSs (Atanassov, 1986) play the role of basic elements reflecting preference values or judgements of decision makers. Li (2005), designed a number of linear programming models and introduced corresponding decision making methods by means of IFSs. Liu and Wang (2007), proposed new series of score functions to be applied to the MCDM problems in accordance with the evaluation functions and the intuitionistic fuzzy point operators. Based on interval-valued IFSs, Chen, Wang, and Lu (2011) developed an approach of multi-criteria group decision making. However, comparatively, very few studies have been focused on the MCDM problems under the hesitant fuzzy environment. Moreover, in the process of decision making, hesitancy and uncertainty are generally considered as unavoidable problems. To express the evaluation information of decision makers more objectively, a number of tools have been developed in the literature, including fuzzy set (Zadeh, 1965), intuitionistic fuzzy set (Atanassov, 1986) and fuzzy multiset (Miyamoto, Liu, & Kunii, 2000; Yager, 1986), interval-valued fuzzy set (Zadeh, 1975), linguistic fuzzy set (Xu, 2004a; Xu, 2004b) and type-2 fuzzy set (Dubois & Prade, 1980).

3. Research methodology

This paper reviews the literature to recognize 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 FMCDM methods. To this end, an extensive search was carried out to find FMCDM in titles, abstracts, keywords, and research methodologies of the papers. This paper attempts to document the exponentially grown interest in the FMCDM methods and provide a state-of the-art review of the literature regarding the FMCDM applications and methodologies. According to a classification scheme, a reference repository, including a total of 403 published papers in more than 150 journals since 1994, has been established. The papers are classified in terms of the application areas, publication year, the authors' nationality, the journal's name, and other FMCDM methods. The present paper 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 FMCDM methods, and the identification of issues to be studied in future. Additionally, two new perspectives are taken into consideration to review the articles, namely categorization of the articles into four main fields (business, science, engineering, and technology) and examination of the type of study (FMCDM utilizing research, FMCDM developing research, FMCDM proposing research).

In particular, we targeted six library databases: Springer, ScienceDirect, ProQuest, Emerald, John Wiley, and Taylor & Francis, covering the most important journals in four main fields. Items such as doctoral dissertations, master's theses, textbooks, conference proceeding papers, and unpublished papers were ignored in this review. For this review, the primary data were collected from 1081 cited articles related to MCDM and fuzzy MCDM methods published since 1994. For choose 1081 scholarly journal papers 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 papers on FMCDM have been published since 1994; 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 papers could not be downloaded; for that reason, they were overlooked in this survey. After reviewing each paper, the paper was summarized and highlighted. An article is taken into consideration in this review if it discusses thoroughly the application and development of FMCDM.

MCDM and fuzzy MCDM are the most well-known branches of decision making. In the decision making approach, the selection is made from amongst the decision alternatives that are described by their attributes. Over time, a large number of MCDM methods 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 paper, for identify and finding the scholarly papers related to DM methods in mentioned databases we have searched several keywords, these keywords were, MCDM, fuzzy MCDM, DM (Decision Making), AHP & fuzzy AHP, TOPSIS & fuzzy TOPSIS, VIKOR & fuzzy VIKOR, ELECTRE & fuzzy ELECTRE, DEMATEL & fuzzy DEMATEL, ANP & fuzzy ANP, PROMETHEE, FWA, MCGDM, MCDA, OWA, SAW, FDM, Entropy & fuzzy Entropy, Hybrid FMCDM, Hybrid MCDM, and So on. We have searched these keywords because some articles have integrated MCDM methods with fuzzy numbers and mentioned in the research methodology parts. After primary search and collecting these scholarly articles, the articles related to fuzzy numbers and fuzzy set theory were selected.

4. Results

4.1. Classifications and observations

This survey is based on a literature review and classification of international journal articles from 1994 to 2014. The majority of the journals are specialist journals in the fuzzy and MCDM journal. For the purpose of this part of paper, some of journals are listed based on publishers, and some journals (e.g., Emerald, John Wiley, Springer and Tylor and Francis expect ScienceDirect) are integrated based on their publishers.

Research on FMCDM continued and found many applications to different fields. Multi Criteria Decision Making (MCDM) provides strong decision making in domains where selection of the best alternative is highly complex. This paper reviews the main streams of considerations in multi criteria decision making theory and practice in detail, and it is mainly 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 fuzzy multi criteria decision making 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 analyzing different scopes of the criteria, weights of the criteria, and the selection of the optimum ones using any multi criteria decision making techniques.

This survey investigates the developments of various methods of FMCDM and its applications. In our daily life, many decisions are being 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 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. 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 works, 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 FMCDM methods provide better performance in cases such as supplier chain management in business applications, safety assessment in marine engineering, watershed location, and urban distribution centers in public sectors.

4.2. Field of category

Due to wide range of applications of fuzzy MCDM in the real world, there is a strong motivation to categorize these applications across several areas and particular sub-areas. The studies that have used FMCDM are categorized into three groups: FMCDM utilizing research, FMCDM developing research, and FMCDM proposing research. To identify the differences and similarities, the 403 papers were categorized into four fields: (1) science, management and business, engineering, and technology. In case of the papers that could fall into more than one category, based on the targeted audience defined by the paper's objectives, the best possible choice was selected. This ensured the absence of any duplication in the classification scheme. In the following sections, the papers are briefly presented and each topic is further summarized using tables corresponding to their sub-areas. In each table, the papers are summarized and highlighted according to their introductions, research methods, and the results of the study. Similarly, previous studies (e.g., Behzadian et al. (2012)) have categorized TOPSIS papers based on area of applications like manufacturing systems, supply chain issue, business and management, and so on.

4.3. Engineering field

In this survey, engineering was considered as a field that has mostly used the fuzzy MCDM methods and approaches. In this paper, engineering fields involve several specific sub-fields, some recent applications of fuzzy MCDM approaches in including, civil engineering (Bagočius, et al., 2014; Dadelo et al., 2014; Yazdani-Chamzini et al., 2014), industrial engineering (Avikal, Jain, & Mishra, 2014; Avikal, Mishra, & Jain, 2014; Keskin, 2014; Mokhtari, Alinejad-Rokny, & Jalalifar, 2014), computer science (Herrmann & Herrmann, 2014; Kaya & Kahraman, 2014; Yazdani-Chamzini, 2014), electrical engineering (Kurt, 2014), and mechanical engineering (Azadnia, Saman, & Wong, 2014; Bairagi, Dey, Sarkar, & Sanyal, 2014; Hadi-Vencheh & Mohamadghasemi, 2014). Li, Jin, and Wang (2014), have used TOPSIS and QFD for selection and evaluation of KMS under fuzzy environment. Baležentis and Baležentis (2014), attempted to identify the role MOORA and MULIMOORA play in engineering areas for technological and economic development studies to be conducted in future. Wang and Wu (2014), have applied F-AHP, F-DEMATEL and FDM for evaluation of PLC. Kubler et al. (2014), employed F-AHP for selection of data in communicating material. Zavadskas, Antucheviciene, et al. (2014), developed WASPAS and results compared with COPRAS-IVIF-TOPSIS-IVIF and IFOWA for improve of WPM and WSM accuracy. Zavadskas, Turskis, et al. (2014), used ARAS-F and AHP for solve of problems in construction site selection in Eastern Baltic see. Bairagi et al. (2014), have employed F-AHP, F-VIKOR- F-TOPSIS and COPRAS-G for selection of robots. Mokhtarian, Sadi-nezhad, and Makui (2014a) and Mokhtarian, Sadi-nezhad, and Makui (2014b) proposed IVF-VIKOR and IVF-TOPSIS for solve problems in selection of facility location. Anojkumar, Ilangkumaran, and Sasirekha (2014), have employed FAHP-VIKOR, FAHP-PROMTHEE, FAHP-TOPSIS and FAHP-ELECTRE for selection of material in sugar industry. Rabbani, Zamani, Yazdani-Chamzini, and Zavadskas (2014), implemented of fuzzy COPRAS, ANP and SBSC for evaluation of performance in Iranian oil companies. Tadić, Zečević, and Krstić (2014), Utilized fuzzy ANP, fuzzy VIKOR and fuzzy DEMATEL for selection of city logistics. Hashemian, Behzadian, Samizadeh, and Ignatius (2014), have applied F-AHP and F-PROMETHEE for assessment of supplier process.Ghorabaee, Amiri, Sadaghiani, and Goodarzi (2014), used of F-COPRAS and interval type-2 for selection of supplier. Kucukvar, Gumus, Egilmez, and Tatari (2014), have applied F-ENTROPY and TOPSIS for ranking of life cycle sustainability performance. Altuntas, Selim, and Dereli (2014), utilized F-DEMATEL for solve problem in facility layout production systems. Yeh, Pai, and Liao (2014), have used F-AHP and F-DEMATEL for identifying the critical factors in NPD. Zare Mehrjerdi (2014), implemented of SAW, TOPSIS and QSPM in selection of strategic system. Akdag, Kalaycı, Karagöz, Zülfikar, and Giz (2014), applied AHP, Yager's min–max and TOPSIS for evaluation of service quality in hospital. As an early study in engineering, Simões-Marques et al. (2000), evaluated technical and operational factors for repair of equipment under battle conditions by employed FMADM methodology.

In this survey, the researchers have reviewed a total of 217 article papers in different fields of engineering. According to the obtained results, industry engineering was ranked as the first field in the publication of papers among other fields. In addition, based on review findings, most of the sub-fields in industrial engineering were related to supply chain issues. This result was also confirmed by other scholars (e.g., Behzadian et al. (2012), indicating that, in the TOPSIS application, most of review papers were related to supply chain issues. The results of this field has shown that in the type of FMCDM utilizing research 165 (76%), 39 (17.97%) papers are in the type of FMCDM developing research, 11 papers (5.07%) were FMCDM proposing research. Moreover, in case of the publication year, 42 papers were published in 2014, 32 papers in 2013, 25 papers in 2012, 39 papers in 2011, 26 papers in 2010, 18 papers in 2009, 13 papers in 2008, 10 papers in 2007, four papers in 2006, two papers in 2005, two papers in 2004, one paper in 2003, two papers in 2002 and one paper in 1994. In addition, in case of tools and approaches, 90 papers have employed fuzzy TOPSIS and combined it with other methods, 102 papers have employed fuzzy AHP and combined it with other methods, 32 papers have employed fuzzy ANP and combined it with other methods, 16 papers have employed fuzzy VIKOR and combined it with other methods, 11 papers have employed ELECTRE and combined it with other methods, 13 papers have employed DEMATEL and combined it with other methods, 10 papers have employed PROMETHEE and combined it with other methods, and 32 papers have employed other combined tools and approaches such as ARAS, WASPAS.

4.4. Management and business field

In the field of management and business, 122 studies have applied fuzzy MCDM tools and applications. In this category, there were some specific areas of management and business, including quality management (Amirzadeh & Shoorvarzy, 2013; Benítez, Martín, & Román, 2007; Tseng, 2009b), strategy management issues (Fouladgar, Yazdani-Chamzini, Lashgari, Zavadskas, & Turskis, 2012; Liou, Tzeng, Tsai, & Hsu, 2011), human resource (Dincer & Hacioglu, 2013), marketing (Lin, Lee, & Chen, 2009), risks management (Bayrakdaroğlu & Yalçın, 2013; Ganguly & Guin, 2013), information management (Aliei, Sazvar, & Ashrafi, 2012; Kahraman, Engin, Kabak, & Kaya, 2009), organizational performance (Cho, Lee, Ahn, & Hwang, 2012; Rostamzadeh & Sofian, 2011), knowledge management (Chen & Pang, 2010; Li, 2013), economic issues (Baležentis, Baležentis, & Misiunas, 2012), and other fields of management and business. Liu, Qin, Mao, and Zhang (2014), employed F-VIKOR for personal selection in HRM section of organization. Zamani, Rabbani, Yazdani-Chamzini, and Turskis (2014), have used ARAS-F and ANP for extension of brand in marketing strategies. Hajiagha, Mahdiraji, Zavadskas, and Hashemi (2014), developed F-VIKOR for solve problem in minimizing in ideal and anti-ideal solution. Zhang and Xu (2014), extended

Table 1
Summary of applications of the DM techniques.

DM techniques	Frequency of application	Percentage (%)
Hybrid FMCDM	141	13.04
Hybrid MCDM	215	19.89
AHP	171	15.82
Fuzzy AHP	103	9.53
Fuzzy TOPSIS	79	7.31
TOPSIS	80	7.40
ANP	38	3.52
Fuzzy ANP	26	2.41
PROMETHEE	20	1.85
OWA	28	2.59
DEMATEL	30	2.78
VIKOR	22	2.04
MCGDM	16	1.48
ELECTRE	10	0.93
Fuzzy VIKOR	16	1.48
MCDA	7	0.65
Fuzzy ELECTRE	8	0.74
Fuzzy DEMATEL	9	0.83
Fuzzy PROMETHEE	5	0.46
FWA	1	0.09
Fuzzy ENTROPY	4	0.37
Other	52	4.81
Total	1081	100.00

Table 2
Distribution based on fuzzy AHP.

Authors	Type of study	Tools and approaches
Abdullah and Najib et al. (2014)	Approach proposed	Proposed new scale of preference based on IVIF-AHP for decision making problems
Vahdat, Smith, and Amiri (2014)	Approach developed	Implemented of F-AHP for ranking risk factors for assessment of performance
Kubler et al. (2014)	Utilized approach	Employed F-AHP for selection of data in communicating material
van de Kaa, Rezaei, Kamp, and de Winter (2014)	Utilized approach	Used F-AHP for selection of photovoltaic technology system
Azadnia et al. (2014)	Utilized approach	Employed F-AHP and RBWF methods for selection of sustainable supplier
Dabbaghian, Hewage, Reza, Culver, and Sadiq (2014)	Utilized approach	Used F-AHP for evaluation of performance in green roof systems
Abdullah and Najib (2014)	Approach presented	Presented a new IF-AHP for selection of energy technology
Dragović, Turajlić, Radojević, and Petrović (2014)	Utilized approach	Applied F-AHP for solving problems in the web service
Gürbüz, Albayrak, and Alaybeyoğlu (2014)	Utilized approach	Employed F-AHP for analysis of marketing decisions and marketing strategies for development of new product
Kahraman, Süder, and Kaya (2014)	Utilized approach	Used F-AHP for assessment of investment in the health research
Roy, Ray, and Pradhan (2014)	Utilized approach	Applied F-AHP for selection of process of non-traditional machining
Najafi et al. (2014)	Utilized approach	Applied F-AHP for mineral prospectivity mapping in the eastern of Iran
Tansel İç, Yurdakul, and Dengiz (2013)	Utilized approach	Using a FAHP approach for robot selection
Vafai, Hadipour, and Hadipour (2013)	Utilized approach	Applied the FAHP in GIS environment for the sensitive coastal areas in Iran
Gülgen (2013)	Utilized approach	Employed FAHP weights in the road network hierarchy makes
Ganguly and Guin (2013)	Utilized approach	Using F-AHP for understanding of supply risks evaluation
Ertay, Kahraman, and Kaya (2013)	Utilized approach	Using FAHP and MACBETH for the evaluation of renewable energy
Bayrakdaroğlu and Yalçın (2013)	Utilized approach	Using FAHP to evaluating of operational risk factors of commercial banks
Ishizaka and Nguyen (2013)	Utilized approach	Application of FAHP for selecting of students bank accounts
Fu, Chang, Kao, Chiu, and Lu (2013)	Utilized approach	Using FAHP for Identification of project training course
Jing, Chen, Zhang, and Peng (2013)	Approach developed	Developed hybrid FSAHP to aid decision making by incorporating fuzzy and stochastic uncertainty
Rezaei, Ortt, and Scholten (2013)	Approach developed	Utilized approach FAHP for evaluation of entrepreneurship orientation
Akadiri et al. (2013)	Utilized approach	Employed FAHP for selection of materials in the building projects
Chou, Pham, and Wang (2013)	Utilized approach	Proposed the FAHP regression-based simulation for bidding strategy to support decision-making
Tan, Aviso, Huelgas, and Promentilla (2013)	Approach developed	Proposed a FAHP variant to selection of process engineering problems
Calabrese, Costa, and Menichini (2013)	Utilized approach	Application of FAHP for assets of intellectual capital
Chou, Liang, and Chang (2013)	Approach developed	Presented a new FAHP method, based on the concept of possibility extent, to solve the FMCDM problem
He, Ho, Man, and Xu (2012)	Utilized approach	Proposed FAHP for solve the problems of multi-criteria transshipment
Tsai and Lin (2012)	Utilized approach	Applied FAHP for the alternatives on the basis of the indices of the worldwide best indicators
Sevkli et al. (2012)	Utilized approach	Using of AHP for rank of SWOT factors
Zheng, Zhu, Tian, Chen, and Sun (2012)	Utilized approach	Applied FAHP for work assessment in humid and hot environments
Javanbarg et al. (2012)	Utilized approach	Implemented FAHP for evaluation and optimization of swarm particle
Gao and Hailu (2012)	Utilized approach	Used FAHP to evaluate of fishing recreational in the system of coral reef
Duru, Bulut, and Yoshida (2012)	Utilized approach	Used RS-FAHP to improve traditional AHP by employ regime switching model
Gao et al. (2012)	Approach developed	Developed hierarchical FAHP for distribution of energy-efficient clustering algorithm
Bilgen and Şen (2012)	Utilized approach	Using FAHP for selection of Six Sigma projects
Shakouri and Tavassoli (2012)	Approach presented	Composition of a FAHP and a FIS to differentiate between the criteria and attributed weightings to the criteria
Gao and Hailu (2012)	Utilized approach	Using FAHP for evaluation approach to facilitate multi-criteria decision making
Cho et al. (2012)	Utilized approach	Applied FAHP for performance measurement of service supply chain
Lin and Twu (2012)	Utilized approach	Implemented of F-AHP for evaluation of fashion trend systems
Yueh-Hsiang Chen and Chao (2012)	Utilized approach	Applied of FAHP for vendor selection
Ju, Wang, and Liu (2012)	Utilized approach	Applied of FAHP and 2-tuple fuzzy linguistic to evaluation of response capacity
Samvedi, Jain, and Chan (2012)	Utilized approach	Integrated the FAHP and grey relational analysis approaches for the selection of a machine tools
Büyüközkan (2012)	Utilized approach	Applied a FAHP to rank the green suppliers
Das, Sarkar, and Ray (2012)	Utilized approach	Using COPRAS methodology and FAHP to measure relative performance of Indian technical institutions
Rajput, Milani, and Labun (2011)	Approach developed	Developed FAHP for statistical weighting and time dependency of decisions
Labib (2011)	Utilized approach	Comparison of FAHP and fuzzy logic for selection of supplier
Li, Shi, and Wang (2011)	Approach proposed	Proposed FAHP for agile improvement system by using the action diagram and ECNN
Lu and Wang (2011)	Utilized approach	Application of FAHP to evaluation of project factors and criteria for ICP project
Zhang, Gu, Gu, and Zhang (2011)	Utilized approach	Utilized approach FAHP and LCA for performance evaluation in building energy conservation
Zangoueinezhad and Moshabaki (2011)	Utilized approach	Using F-AHP for analysis of university performance criteria
Tseng, Lin, and Chen (2011)	Utilized approach	Employed F-AHP for priority and identify of e-learning systems efficiency
Mikaeil, Ataei, and Yousefi (2011)	Utilized approach	Application of FAHP for predicting of vibration rock sawing
Chiouy, Chou, and Yeh (2011)	Utilized approach	Using of F-AHP for ranking of supplier selection and evaluation
Zangoueinezhad, Azar, and Kazazi (2011)	Utilized approach	Using FAHP for supply chain competitiveness positioning
Ustundag and Serdar Kilinc (2011)	Utilized approach	Applied FAHP to select the best science park
Büyüközkan, Çifçi, and Güleryüz (2011)	Utilized approach	Using FAHP to evaluation of service quality framework
Padma and Balasubramanie (2011)	Utilized approach	Applied FAHP for the forecasting on neck and shoulder pains
Durán (2011)	Utilized approach	Applied FAHP for selection computer-aided maintenance management systems
An, Chen, and Baker (2011)	Utilized approach	Application FAHP in railway risk information system
Lee, Mogi, Lee, and Kim (2011)	Utilized approach	Employed FAHP for rank weights of hydrogen energy technology in the sector of hydrogen

(*continued on next page*)

Table 2 (*continued*)

Authors	Type of study	Tools and approaches
		economy
Majumdar (2010)	Utilized approach	Used FAHP for raw material selection in industry of textile spinning
Lee, Mogi, Lee, Hui, and Kim (2010)	Utilized approach	Utilized approach FAHP and DEA for R&D efficiency performance in the national hydrogen energy
Shen et al. (2010)	Utilized approach	Utilized approach FAHP for solution of problems in Renewable Energy Development Bill
Şen and Çınar (2010)	Utilized approach	Combined FAHP and max–min approach for pre-allocation and evaluation of operators
Kahraman, Beskese, and Kaya (2010)	Utilized approach	Application of FAHP for the selection among ERP outsourcing alternatives
Şen, Şen, and Başlıgil (2010)	Utilized approach	Application of FAHP and max–min method for supplier pre-selection
Vadrevu, Eaturu, and Badarinath (2010)	Utilized approach	Integrated FAHP and GIS for evaluation of forest risk fire
Kahraman and Kaya (2010)	Utilized approach	Suggested FAHP for the selection of energy policies indicators
Rezaei and Dowlatshahi (2010)	Utilized approach	Applied fuzzy logic and AHP for classification inventory
Chen, Wang, Chen, and Lee (2010)	Utilized approach	Application FAHP for selection of R&D strategic alliance partner"
Chamodrakas, Batis, and Martakos (2010)	Utilized approach	Application of FAHP for selection of supplier in electronic marketplaces
Ayağ (2010)	Utilized approach	Applied the FAHP for the organization real-life product
Ali, Shil, Nine, Khan, and Hoque (2010)	Utilized approach	Using VSFI by integrating FCM algorithm with AHP for vendor selection
Heo, Kim, and Boo (2010)	Utilized approach	Using the FAHP to establish the criteria and factors for renewable energy
Amir Azadeh, Osanloo, and Ataei (2010)	Utilized approach	Using fuzzy FAHP approach Nicholas technique to selection of mining method
Jaskowski, Biruk, and Bucon (2010)	Approach developed	Application of FAHP for facilitates defining criteria weights by aggregation
Güngör, Serhadlıoğlu, and Kesen (2009)	Utilized approach	Proposed FAHP for personnel selection system
Cebeci (2009)	Utilized approach	Using of FAHP for compare ERP systems solutions
Li and Huang (2009)	Utilized approach	Combined TRIZ and FAHP for designing the automated manufacturing systems
Naghadehi et al. (2009)	Utilized approach	Applied FAHP for selecting and best criteria underground mining in Iran
Sun et al. (2009)	Utilized approach	Used FAHP for determine weights for evaluating of dimensions
Tang (2009)	Utilized approach	Applied FAHP and AIP for budget allocation for aerospace company
Lin et al. (2009)	Utilized approach	Applied FAHP for evaluation of service performance in foreign travel industry
Tseng, Lin, and Chiu (2009)	Utilized approach	Applied FAHP for successful implementation and adoption of CP in Taiwan
Lee (2009)	Utilized approach	Evaluated of buyer–supplier forms based on FAHP technique
Tseng, Chiu, and Chen (2009)	Utilized approach	Using AHP, fuzzy multi-criteria and DEA to determine the business performance
Chang, Wu, and Chen (2008)	Utilized approach	Employed FAHP for tackling the imprecision of silicon wafer slicing and uncertainty
Cakir and Canbolat (2008)	Utilized approach	Using FAHP for inventory classification system
Chang, Hung, Li, and Hsu (2008)	Utilized approach	Employed FAHP to for use in managing of strategies industrial development
Dağdeviren and Yüksel (2008)	Utilized approach	Employed FAHP to determine FBR in work systems
Lee, Chen, and Chang (2008)	Utilized approach	FAHP approach applied to evaluation of BSC performance indicators
Chiang, Guo, and Pai (2008)	Utilized approach	Utilized F-AHP to determine levels of WIP acceptable set
Wang, Luo, and Hua (2008)	Review	Reviewed on FAHP and its applications
Wang and Chen (2008)	Utilized approach	Using FAHP to derive pairwise comparison matrices
Pan (2008)	Approach developed	Employed FAHP approach for selection of the suitable bridge construction
Chan and Kumar (2007)	Approach developed	Using of FEAHP for selection of global supplier
Wang, Chu, and Wu (2007)	Utilized approach	Employed FAHP to selecting the best strategies of maintenance
Ma, Chen, and Wu (2007)	Utilized approach	Combined FAHP and image compositing technique for choosing the optimum product
Kreng and Wu (2007)	Utilized approach	Employed FAHP for evaluation of KPS development tools
Kang and Lee (2007)	Utilized approach	Construct an FAHP method and entropy weight for rank of different priority mixes
Bozbura, Beskese, and Kahraman (2007)	Utilized approach	Proposed FAHP for measurement indicators of human capital
Chan, Chan, Chan, and Humphreys (2006)	Utilized approach	Using FAHP for classification of technology criteria selection
Ayağ (2005)	Utilized approach	Using FAHP for NPD environment evaluation
Kapoor and Tak (2005)	Utilized approach	Application of FAHP to selection of robot problems
Cheng, Chen, and Yu (2005)	Utilized approach	Employed F-AHP for evaluating of strategy in broadband services
Büyüközkan and Feyzıog˜lu (2004)	Utilized approach	Employed FAHP for selection of strategy problem for new product development
Hsieh, Lu, and Tzeng (2004)	Utilized approach	Using FAHP for selection of design and planning alternatives in public office building
Kahraman, Cebeci, and Ulukan (2003)	Utilized approach	Employed the FAHP for selection of suppliers
Kuo, Chi, and Kao (2002)	Utilized approach	Using of FAHP to develop a decision support system for locating a new CVS
Cheng (1997)	Approach proposed	Developed FAHP for evaluation of naval tactical missile systems
Cheng and Mon (1994)	Approach developed	Proposed FAHP for evaluating weapon systems

Table 3
Distribution based on fuzzy ELECTRE.

Authors	Type of study	Tools and approaches
Vahdani, Mousavi, Tavakkoli-Moghaddam, and Hashemi (2013)	Proposed approach	Extension of the ELECTRE, for FMCGDM problems
Devi and Yadav (2013)	Utilized approach	Applied F-ELECTRE for selecting of the best plant locations problems
Rouyendegh and Erkan (2013)	Utilized approach	Using F-ELECTRE for the selection of academic staffs
Hatami-Marbini, Tavana, Moradi, and Kangi (2013)	Utilized approach	Present a fuzzy group ELECTRE method for health assessment safety
Sepehriar, Eslamipoor, and Nobari (2013)	Approach developed	Employed F-ELECTRE for selection of the best supplier
Vahdani and Hadipour (2011)	Approach developed	Presented F-ELECTRE for solving MCDM problems based on interval-value
Wu and Chen (2011)	Utilized approach	Proposed intuitionistic F-ELECTRE, for solving MCDM problems
Sevkli (2010)	Utilized approach	Proposed F-ELECTRE to determine the criteria of supplier selection
Montazer, Saremi, and Ramezani (2009)	Utilized approach	Employed the F-ELECTRE III for rank the vendors based on the DSS evaluations of the vendors

TOPSIS based on Pythagorean under fuzzy environment. Moghimi and Anvari (2014), have employed F-AHP and TOPSIS for evaluating of performance in cements firms. Safaei Ghadikolaei, Khalili Esbouei, and Antucheviciene (2014), have employed F-AHP, F-COPRAS, F-VIKOR, and ARAS-F for performance evaluation in Iranian companies. In this category, some previous studies, for example, (Ma, Chang, & Hung, 2013), integrated Delphi method and fuzzy AHP for the selection of technology process. Tsai, Chang, and Lin (2010), used fuzzy AHP and Delphi for evaluating the performance in hospital organization. Tavana, Zandi, and Katehakis (2013), have applied group FANP and TOPSIS to assess a community's overall e-government readiness. From among 122 studies, 10 (8.20%) papers have been published in 2014, 19 (15.57%) papers have been published in 2013, 22 (18.03%) papers in 2012, 26 (21.31%) papers in 2011, 13 (10.66%) papers in 2010, 14 (11.48%) papers in 2009, 8 (6.56%) papers in 2008, three papers (2.46%) in 2007, two papers (1.64%) in 2006, two papers (1.64%) in 2004, one paper (0.82%) in 2002, two papers (1.64%) in 2000. In case of the type of study, most previous studies have been published in field of management and business using fuzzy MCDM, the numbers of papers that FMCDM utilizing research are 107 (87.70%) papers, 13 (10.66%) papers as FMCDM developing research, in the FMCDM proposing research only two paper (1.64%) published, and one paper (0.82%) was as review paper. The percentages of this section show that most of the studies in the management and business field have implemented the fuzzy MCDM as tools and methods for their decision making problems rather than developing and proposing these fuzzy MCDM tools and applications. In the category of tools and application, researchers in management and business fields have applied 45 papers fuzzy TOPSIS and mixed it with other methods, 64 papers have used fuzzy AHP and mixed it with other methods, 15 papers have used fuzzy ANP and mixed it with other methods, 13 papers have used fuzzy VIKOR and mixed it with other methods, six papers have used fuzzy DEMATEL and mixed it with other methods, and 15 papers have used other mixed tools and applications such as ARAS-F, F-ELECTRE, F-COPRAS and so on.

4.5. Science and technology field

Science and technology also was two of the four categories of this survey, which includes 63 papers. In this category there were some specific fields of science, include mathematic (Abdullah & Najib, 2014a; Abdullah & Najib, 2014b; Kelemenis & Askounis, 2010), energy and environmental (Akadiri, Olomolaiye, & Chinyio, 2013; Bagočius et al., 2014; Kabak, Köse, Kırılmaz, & Burmaoğlu, 2014; Shen, Lin, Li, & Yuan, 2010), transportation (Awasthi & Chauhan, 2011), natural resource and environmental management (Lee, Mogi, Kim, & Gim, 2008; Yazdani-Chamzini, 2014) and operations research (Antuchevičiene, 2005; Sun, Lin, & Tzeng, 2009; Zavadskas, Antucheviciene, et al., 2014), and other areas related to the science and technology category .Najafi, Karimpour, and Ghaderi (2014), applied F-AHP for mineral prospectively mapping in the eastern of Iran. Ribeiro, Falcão, Mora, and Fonseca (2014), proposed algorithm by applied FMCDM and mixture aggregation operators based on weighting functions for spacecraft landing with hazard avoidance. Hadi-Vencheh and Mohamadghasemi (2014), utilized F-TOPSIS, F-VIKOR and FWA selection of materials equipment problems. Gao, Jin, Song, Xu, and Wang (2012), developed hierarchical FAHP for distribution of energy-efficient clustering algorithm. Javanbarg, Scawthorn, Kiyono, and Shahbodaghkhan (2012), implemented FAHP for evaluation and optimization of swarm particle. Gao and Hailu (2012), used FAHP to evaluate of fishing recreational in the system of coral reef. Naghadehi, Mikaeil, and Ataei (2009), applied FAHP for selecting and best criteria underground mining in Iran. Results of these categories showed that From 63 published article papers, 49 studies (77.78%) were FMCDM utilizing research, 11 studies (17.46%) were FMCDM developing research and methods and three studies (4.76%) have proposing new approaches and methods based on fuzzy MCDM tools and applications. These studies have published in the following years: 16 papers (25.40%) in 2014, six papers (9.52%) in 2013, nine papers (14.29%) in 2012, 12 papers (19.05%) in 2011, eight papers (12.70%) in 2010, and three papers (4.76%) in 2009, two papers (3.17%) in 2008, two papers (3.17%) in 2007, one paper (1.59%) in 2006, three papers (4.76%) in 2005, and one paper (1.59%) in 1997. In case of the implementation of tools and applications in this category, 15 cases have utilized fuzzy TOPSIS and integrated it with other methods, 32 cases have utilized fuzzy AHP and integrated it with other methods; eight papers have utilized fuzzy DEMATEL and integrated it with other methods, five studies have utilized fuzzy VIKOR and integrated it with other methods.

Table 4
Distribution based on fuzzy DEMATEL.

Authors	Type of study	Tools and approaches
Keskin (2014)	Utilized approach	Applied fuzzy C-means clustering and F-DEMATEL for selection and evaluation supplier performance
Jeng and Tzeng (2012)	Utilized approach	Applies DEMATEL technique to explore the UTAUT variables
Wu (2012)	Utilized approach	Used F-DEMATEL to success implementation of KM based on CSF's
Zhou, Huang, and Zhang (2011)	Utilized approach	F-DEMATEL to figure out CSFs in accordance with potentially numerous criteria
Lee, Li, Yen, and Huang (2011)	Approach developed	Developed F-DEMATEL for evaluation of technology acceptance models problems
Tseng (2010)	Utilized approach	Employed F-DEMATEL for evaluation of EKMC firms
Tseng (2009)	Utilized approach	Application of F-DEMATEL to ranking of real estate agent service quality expectation
Lin and Wu (2008)	Utilized approach	Proposed F-DEMATEL to selection of R&D project in Taiwanese companies
Wu and Lee (2007)	Utilized approach	Used F-DEMATEL for better promoting the competency development of global managers

Table 5
Distribution based on fuzzy PROMETHEE.

Authors	Type of study	Tools and approaches
Gupta, Sachdeva, and Bhardwaj (2012)	Utilized approach	Employed the F-PROMETHEE method for logistic provider selection
Yilmaz and Dağdeviren (2011)	Approach developed	Combined zero–one goal programming and F-PROMETHEE for equipment selection
Chen, Wang, and Wu (2011)	Utilized approach	Applied F-PROMETHEE to evaluate suppliers
Saidi Mehrabad and Anvari (2010)	Utilized approach	Application of fuzzy C-Means and F-PROMETHEE for evaluation of FMS
Halouani, Chabchoub, and Martel (2009)	Approach developed	Integrated linguistic 2-tuples and PROMETHEE for selection of facilitate project task

Table 6
Distribution based on fuzzy TOPSIS.

Authors	Type of study	Tools and approaches
Zagorskas et al. (2014)	Utilized approach	Employed fuzzy gray TOPSIS for selection of best alternatives in the brick wall insulation
Liu, Ren, Wu, and Lin (2014)	Utilized approach	Implemented of ITL-TOPSIS for selection of optimal robots in manufacturing
Kurt (2014)	Utilized approach	Used of F-TOPSIS and Choquet fuzzy for selection of nuclear power plant location
Mokhtari et al. (2014)	Utilized approach	Employed of F-TOPSIS for selection of well control system in oil industry
Wang (2014)	Approach developed	Developed FMCDM to solve problems in FMCDM based on TOPSIS
Mokhtarian, Sadi-nezhad, and Makui (2014)	Approach proposed	Proposed IVF-TOPSIS for solve problems in selection of facility location
Li et al., 2014	Utilized approach	Used TOPSIS and QFD for selection and evaluation of KMS under fuzzy environment
Mokhtarian (2014)	Approach developed	Extended the F-TOPSIS for solve problem in MCDM methods based on previous studies
Maldonado-Macías, Alvarado, García, and Balderrama (2014)	Utilized approach	Used F-TOPSIS for assessment of ergonomic compatibility in advance manufacturing technology
Arabzad, Ghorbani, Razmi, and Shirouyehzad (2014)	Utilized approach	Employed F-TOPSIS for selection of supplier and allocation problem
Zhang and Xu (2014)	Approach developed	Extended TOPSIS based on Pythagorean under fuzzy environment
Kilic (2013)	Approach developed	Integrated of FTOPSIS and linear programming model for selection of suppliers
Roshandel, Miri-Nargesi, and Hatami-Shirkouhi (2013)	Utilized approach	Using the hierarchical FTOPSIS for selection of suppliers in Iran
Kim, Chung, Jun, and Kim (2013)	Utilized approach	Developed an F-TOPSIS for treated wastewater (TWW)
Dymova, Sevastjanov, and Tikhonenko (2013)	Approach Proposed	Proposed a new TOPSIS method which is free of known methods limitations and heuristic assumptions
Wang and Chan (2013b)	Utilized approach	Using hierarchical F-TOPSIS to evaluation of different green initiatives
Wang and Chan (2013)	Utilized approach	Implemented of hierarchical F-TOPSIS for evaluation of green supply chain performance
Li (2013)	Utilized approach	Using F-TOPSIS for evaluation and selection of knowledge management system
Amirzadeh and Shoorvarzy (2013)	Utilized approach	Application of FTOPSIS for evaluation of banks quality elements by SERVQUAL
Singh and Benyoucef (2013)	Utilized approach	Using F-TOPSIS for coordination of supply chain, i.e., selection problems
Shen, Olfat, Govindan, Khodaverdi, and Diabat (2013)	Utilized approach	Applied F-TOPSIS to generate an overall performance score for supplier
Vinodh, Mulanjur, and Thiagarajan (2013)	Utilized approach	Proposed F-TOPSIS to select the criteria for sustainability among several sustainability criteria
Maity and Chakraborty (2013)	Utilized approach	Applied F-TOPSIS to solve grinding wheel abrasive material selection problem
Dymova, Sevastjanov, and Tikhonenko (2013)	Approach developed	Extended F-TOPSIS for compromise solution to a FMCDM problem
Tansel İç (2012)	Utilized approach	Proposed FTOPSIS and LP approaches for the banks to determine the credit risks
Rouhani, Ghazanfari, and Jafari (2012)	Approach developed	Application of F-TOPSIS for business intelligence system
Huang and Peng (2012)	Approach developed	Employed the Fuzzy Rasch in TOPSIS to analyze the TDC in nine Asian countries
Uysal and Tosun (2012)	Utilized approach	Implemented of F-TOPSIS for selection of maintenance systems
Arslan and Çunkaş (2012)	Utilized approach	Applied F-TOPSIS for evaluation performance in Sugar Plants
Vahdani, Mousavi, and Tavakkoli-Moghaddam (2011)	Approach developed	Proposed fuzzy modified TOPSIS for rapid prototyping process selection and the robot selection
Boran, Genç, and Akay (2011)	Approach developed	Extended and proposed the F-TOPSIS to select appropriate personnel among candidates
Chamodrakas, Leftheriotis, and Martakos (2011)	Approach developed	A fuzzy approach for ranking alternatives in MADM problems based on TOPSIS
Awasthi, Chauhan, Omrani, and Panahi (2011)	Utilized approach	Presented an F-TOPSIS for evaluation of service quality in urban transportation systems
Afshar, Mariño, Saadatpour, and Afshar (2011)	Utilized approach	Employed F-TOPSIS for solve the problems in real water resource management in Iran
Awasthi, Chauhan, and Omrani (2011)	Utilized approach	Employed F-TOPSIS for assessment and selection of transportation systems
Yang, Bonsall, and Wang (2011)	Utilized approach	Using F-TOPSIS for vessel selection under uncertain environment
Soner Kara (2011)	Utilized approach	Used F-TOPSIS for ranking and selection of potential suppliers' problems
Singh and Benyoucef (2011)	Utilized approach	Used F-TOPSIS to solution of MCDM problems in selection of supply chain coordination
Kaya and Kahraman (2011)	Approach developed	Modified F-TOPSIS methodology for the selection of the best energy technology
La Scalia, Aiello, Rastellini, Micale, and Cicalese (2011)	Approach developed	Utilized TOPSIS for transplantation of the pancreatic islet
Eraslan and Iç (2011)	Utilized approach	Employed F-TOPSIS for socio-economic level of geographical investment regions
Kelemenis, Ergazakis, and Askounis (2011)	Utilized approach	Extended of F-TOPSIS for selection of support managers
Liao and Kao (2011)	Utilized approach	This study proposes integrated fuzzy TOPSIS and MCGP for supplier selection problem
Torlak, Sevkli, Sanal, and Zaim (2011)	Utilized approach	Using F-TOPSIS for business competition in the Turkish domestic airline industry
Tan (2011)	Approach developed	Developed FGDM using Choquet integral based TOPSIS
Amiri and Golozari (2011)	Proposed approach	Application of F-TOPSIS for critical path by using quality, cost, time, risk criteria
Jiang, Chen, Chen, and Yang (2011)	Approach developed	Proposed F-TOPSIS and Fuzzy BS for solve Group Belief MCDM problems
Krohling and Campanharo (2011)	Utilized approach	Applies F-TOPSIS for GDM in accidents with oil spill in the sea
Iç and Yurdakul (2010)	Utilized approach	Applied F-TOPSIS for model of credit scoring in manufacturing industries
Kelemenis and Askounis (2010)	Utilized approach	Applied F-TOPSIS for personal selection and ranking alternatives
Kaya and Kahraman (2010)	Proposed approach	Modified FTOPSIS for the selection of the energy technology alternatives
Sadi-Nezhad and Khalili Damghani (2010)	Approach developed	Developed a TOPSIS for a FMCGDMP
Cavallaro (2010)	Utilized approach	Proposed F-TOPSIS to investigate the feasibility of utilizing a molten salt
Roghanian, Rahimi, and Ansari (2010)	Proposed approach	Evolution of first aggregation and last aggregation in fuzzy group TOPSIS
Yu and Hu (2010)	Utilized approach	Employed F-TOPSIS method to evaluate the performance of multiple manufacturing plants
(Sun and Lin (2009)	Utilized approach	Application of F-TOPSIS for evaluation of competitive advantages of shopping websites
Saremi, Mousavi, and Sanayei (2009)	Utilized approach	Using F-TOPSIS for selection of TQM external consultant environment
Ashtiani, Haghighirad, and Makui (2009)	Approach developed	Presented new approach of FTOPSIS for solving MCDM problems in which the weights of criteria are unequal
Chu and Lin (2009)	Approach developed	Suggested an F-TOPSIS for the interval arithmetic
Kahraman et al. (2009)	Utilized approach	Application of F-TOPSIS for selection of information systems outsourcing
Zeydan and Çolpan (2009)	Utilized approach	Application of DEA and F-TOPSIS for measurement performance
Athanasopoulos, Riba, and Athanasopoulou (2009)	Utilized approach	Combined the F-TOPSIS and Max–Min set for calculation the ordering value of the alternatives
Yurdakul and İç (2009)	Utilized approach	Using of F-TOPSIS to derive quality indexes for electronic packages

Table 6 (*continued*)

Authors	Type of study	Tools and approaches
Chen and Tsao (2008)	Approach developed	Presented interval-valued F-TOPSIS rankings determined by different distance measures
Wang (2008)	Utilized approach	Utilized F-TOPSIS for evaluation of airlines financial performance
Mahdavi, Mahdavi-Amiri, Heidarzade, and Nourifar (2008)	Approach developed	Designed an F-TOPSIS for obtain the ideal solutions in fuzzy environment
Kahraman, Çevik, Ates, and Gülbay (2007)	Proposed approach	Proposed a fuzzy hierarchical TOPSIS for the evaluation of multi-criteria in the industrial robotic systems
Kahraman, Ates, Çevik, and Gülbay (2007)	Utilized approach	Developed fuzzy hierarchical TOPSIS and applied to an e-service provider selection problem
Benítez et al. (2007)	Utilized approach	Application of F-TOPSIS for service quality measurement in hotel industry
Wang and Lee (2007)	Approach developed	Generalized TOPSIS to FMCGDM in a fuzzy environment
Kahraman, Ates, Çevik, Gülbay, and Erdogan (2007)	Utilized approach	Applied the "Hierarchical F-TOPSIS for selection of logistics information
Wang and Chang (2007)	Utilized approach	Employed F-TOPSIS for evaluation initial training aircraft
Dimova, Sevastianov, and Sevastianov (2006)	Approach developed	Proposed F-TOPSIS for supplier selection problems in the supply chain system
Chen, Lin, and Huang (2006)	Approach developed	Developed F-TOPSIS to deal with the supplier selection problems in the supply chain
Yong (2006)	Utilized approach	Using F-TOPSIS for selection of plant location
Wang and Elhag (2006)	Approach developed	Proposed a F-TOPSIS method for evaluation of risk assessment
Yong and Qi (2005)	Utilized approach	Proposed a new centroid-index ranking method of fuzzy numbers by using TOPSIS
Antuchevičiene (2005)	Approach developed	Developed F-TOPSIS for solving problems in the crisp value to model real-life situations
Karsak (2002)	Approach developed	Developed F-TOPSIS to considering strategic performance and economic criteria
Chen (2000)	Approach developed	Extended the F-TOPSIS for group decision making environment
Chen (2000)	Approach developed	Developed TOPSIS in fuzzy environment for group decision making

Table 7
Distribution based on fuzzy ANP.

Authors	Type of study	Tools and approaches
Rabbani et al. (2014)	Utilized approach	Implemented of fuzzy COPRAS, ANP and SBSC for evaluation of performance in Iranian oil companies
Kabak et al. (2014)	Utilized approach	Employed F-ANP for evaluation of performance in building energy
Gürbüz and Albayrak (2014)	Utilized approach	Used ANP and Choquet Integral under fuzzy environment for assessment of HRM performance
Palanisamy and Zubar (2013)	Utilized approach	Using F-QFD, ANP and mathematical for rank of vendor
Tavana, Momeni, Rezaeiniya, Mirhedayatian, and Rezaeiniya (2013)	Utilized approach	Using of COPRAS-G and FANP for selection of social media platform
Lin (2012)	Utilized approach	Integrated FANP with FMOLP for selection the best suppliers
Kang, Lee, and Yang (2012)	Utilized approach	Applied the FANP for selection of supplier about IC packaging
Vahdani, Hadipour, and Tavakkoli-Moghaddam (2012)	Approach developed	Proposed FANP to solution of MCDM problems
Yang and Chang (2012)	Utilized approach	Applied F-ANP for decision process of customers in bundles selection
Kuo and Liang (2011)	Utilized approach	Using the FANP construct fuzzy weights of all criteria for locations selection
Liou et al. (2011)	Utilized approach	Combined FANP and fuzzy preference programming to selection of strategic alliances partners
Büyüközkan and Çifçi (2011)	Utilized approach	Employed the FANP for selection of supplier with incomplete information
Vinodh, Anesh Ramiya, and Gautham (2011)	Utilized approach	Employed the FANP for selection of supplier in manufacturing organization
Chang, Horng, and Lin (2011)	Utilized approach	Using FANP for experts' knowledge-based systems algorithm
Chang, Horng, and Lin (2011)	Utilized approach	Using F-ANP for evaluation of management decision making
Özgen and Tanyas (2011)	Utilized approach	Proposed the FANP for selection of international roads and broker agencies
Ayağ and Özdemir (2011)	Utilized approach	Using of FANP for evolution the selection of machine tool
Boran and Goztepe (2010)	Utilized approach	Proposed an FANP for evaluation of vendor alternatives
Chen and Pang (2010)	Utilized approach	Using FANP for distribution of existing knowledge to create new knowledge
Vinodh, Gautham, Anesh Ramiya, and Rajanayagam (2010)	Utilized approach	Using the FANP for selection concept selection in agile manufacturing
Ayağ and Özdemir (2009)	Utilized approach	Employed the FANP for selection of ERP software problems
Tseng, Chiang, and Lan (2009)	Utilized approach	Applied FANP for selection the optimal supplier in SCMS
Tuzkaya and Önüt (2008)	Utilized approach	Applied FANP for large-sized real-life problem in the transportation projects
Ayağ and Özdemir (2007)	Utilized approach	Presented FANP for selection of ERP software problem
Mikhailov and Tsvetinov (2004)	Proposed approach	Proposed FANP for imprecision of the service evaluation process and tackling the uncertainty
Pang and Bai (2013)	Utilized approach	Using FANP for selection a supplier alternative and evaluation
Moalagh and Ravasan (2013)	Utilized approach	Using FANP for assessment ERP post-implementation success

4.6. Distribution based on fuzzy MCDM and MCDM tools and approaches

Table 1 shows frequency of both fuzzy MCDM and MCDM tools and approaches. Based on results presented in this table, a total of 1081 studies have employed these two kinds of DM tools and approaches, whereas 403 studies have used fuzzy MCDM and 745 studies have utilized MCDM. This table shows that hybrid FMCDM has been used more than other tools and approaches. The second one is the MCDM tools and approaches and traditional AHP is the third in this ranking. The frequency of other tools and approaches are presented in Table 1.

4.7. Distribution based on fuzzy MCDM tools and approaches

Tables 2–9 show implementation of each fuzzy MCDM tools and approaches. Based on results presented in these tables, a total of 403 studies have employed fuzzy DM tools and approaches, these tables show that fuzzy AHP with 100 papers has been used more than other tools and approaches. The second one is the other

Table 8
Distribution based on fuzzy VIKOR.

Authors	Type of study	Tools and approaches
Mokhtarian et al. (2014)	Approach proposed	Proposed IVF-VIKOR for solve problems in selection of facility location
Liu et al. (2014)	Utilized approach	Employed F-VIKOR for personal selection in HRM section of organization
Hajiagha et al. (2014)	Approach developed	Developed F-VIKOR for solve problem in minimizing in ideal and anti-ideal solution
Kim and Chung (2013)	Utilized approach	Evaluated the vulnerability of the water supply in the South Korean by fuzzy VIKOR approach
Liao and Xu (2013)	Approach developed	Proposed the hesitant F-VIKOR for effective solving MCDM problems
Kumar, Singh, and Dureja (2012)	Utilized approach	Applied the F-VIKOR and CFPR for solution of logistic outsourcing problem
Yücenur and Demirel (2012)	Utilized approach	Applied extended VIKOR for the selection of best solution in Turkish insurance firms
Kuo and Liang (2012)	Utilized approach	Presented F-VIKOR to solve MCDM problems and performances
Jeya Girubha and Vinodh (2012)	Utilized approach	Extended the VIKOR for selection of materials problems
Kuo (2011)	Proposed approach	Proposed F-VIKOR, fuzzy sets and GRA improve levels of service quality
Shemshadi, Shirazi, Toreihi, and Tarokh (2011)	Approach developed	Extended the VIKOR with a mechanism to extract and deploy objective weights based on Shannon entropy concept
Park, Cho, and Kwun (2011)	Approach developed	Extended F-VIKOR for ranking and selection of optimal alternatives
Opricovic (2011)	Approach developed	Developed F-VIKOR for rank of fuzzy numbers
Sasikumar and Haq (2011)	Utilized approach	Proposed the F-VIKOR to determine the best 3PRLP selection process
Vahdani, Hadipour, Sadaghiani, and Amiri (2010)	Approach developed	Presented F-VIKOR for solving MCDM problems based on interval-valued
Chen and Wang (2009)	Utilized approach	Using F-VIKOR for selection partners in IS/IT outsourcing projects

and integrated papers of fuzzy MCDM tools and approaches and fuzzy TOPSIS is the third in this ranking.

4.8. Distribution based on publication year

Fig. 2 presents important evidence based on the frequency of distribution by the year of publication. The results indicate that from 1994 to 2014, the information about the use of fuzzy MCDM and MCDM tools and approaches have grown increasingly. According to the findings of this section, the use of these tools and approaches in 1994 was four papers and this number increased to 10 papers in 1996. Surprisingly, from 2008 to 2009, the numbers of studies have dramatically increased. Although the use of fuzzy MCDM and MCDM tools and approaches have increased in each year, the number of those papers in 2012 (171) have decreased compared to 2011 (176). Another interesting result in this table is about 2013 which previous studies have applied tools and techniques more than other years. This year has the highest number of publications (188). Accordingly, it can be indicated that researchers in different fields and categories use the fuzzy MCDM and MCDM tools and approaches nowadays in their research, and it can be predicted that in coming years, these numbers will increase.

4.9. Author distribution by nationality

Table 10 presents the nationality of the authors who have utilized the fuzzy MCDM and MCDM approaches in their studies. As can be seen, 59 countries have contributed to this survey. In addition, the table reveals that most of the papers are from Taiwan (21.46%), Turkey (12.21%), Iran (11.19%) and China (10.73%). These results with a few differences and similarities were confirmed by other review papers such as Behzadian et al. (2012) that ranked Taiwan as the first country, China as the second, and Iran as the third one.

5. Discussion

This study attempted to review papers published during 20 years (1994–2014) about fuzzy MCDM in popular international journals, which are accessible database systems such as ScienceDirect, Springer, Emerald, John Wiley, ProQuest, and Taylor & Francis. The first aim of this paper was systematically reviewing the studies conducted based on fuzzy MCDM tools and approaches. To this end, in the first step, a total of 1081 published papers about fuzzy MCDM and MCDM were systematically and carefully chosen and summarized based on title, abstract, introduction, research method, and conclusion. In the next step, according to the predefined objective of this study, those papers related to fuzzy MCDM tools and approaches were selected. From 1081 articles, 403 studies (37.28%) have been focused on fuzzy DM tools and approaches and 678 studies (62.72%) have used DM tools and approaches. In this review, the obtained results were analyzed based on six research questions; these questions were (1) which fuzzy and non-fuzzy DM techniques have frequently been applied? (2) Which type of study has applied these fuzzy MCDM techniques? (3) Which one of the four fields (i.e., science, business, technology, and engineering) has used further the fuzzy MCDM techniques types? (4) What kind of fuzzy MCDM techniques have been employed in these years based on the four fields? (5) Which countries have published these fuzzy MCDM tools based on the number of publications in these four fields? And finally, (6) in which year authors have further published fuzzy MCDM tools based on frequency in the four fields? To answer the first question, we considered the results presented in Table 1 that showed the number and percentage of those DM tools and approaches in both fuzzy and non-fuzzy MCDM. This table revealed that hybrid fuzzy MCDM was ranked as the first tool among other tools and approaches; additionally, in the individual tools and approaches, AHP and fuzzy AHP were ranked as the second and third tools. The results obtained for this question were presented in Table 1. To answer the second question, we read the methodology section of each paper very carefully and classified the studies in three types. Based on our reading, some studies have used fuzzy and non-fuzzy DM as tool and technique for solve decision-making problems. Based on our experience and discussions held with some experts on fuzzy and non-fuzzy DM issues about this type of studies, we decided to call this type of study FMCDM utilizing research. Some scholars have attempted to develop fuzzy and non-fuzzy DM tools and approaches based on their objectives; therefore, the FMCDM developing research is considered as the second type of study. Furthermore; our review indicated that some researchers have proposed new approach based on fuzzy and non-fuzzy DM tools and techniques, which we named FMCDM proposing research type. The answers to questions three and four were presented sections 4.3–4.5. These sections indicated that 90 papers have employed fuzzy TOPSIS and combined it with other methods, 102 papers have employed fuzzy AHP and combined it with other methods, 32 papers have employed fuzzy ANP and combined it with other methods, 16 papers have employed fuzzy VIKOR and combined it

Table 9
Distribution based on other fuzzy tools and integrated studies such as F- COPRAS, ARAS-F and F-WASPAS.

Authors	Type of study	Tools and approaches
Akdag et al. (2014)	Utilized approach	Applied AHP, Yager's min–max and TOPSIS for evaluation of service quality in hospital
Zare Mehrjerdi (2014)	Utilized approach	Implemented of SAW, TOPSIS and QSPM in selection of strategic system
Hadi-Vencheh and Mohamadghasemi (2014)	Utilized approach	Utilized F-TOPSIS, F-VIKOR and FWA selection of materials equipment problems
Yazdani-Chamzini et al. (2014)	Utilized approach	Used of AHP, TOPSIS and DEMATEL for investment strategy selection under fuzzy environment
Gil-Lafuente, Merigó, and Vizuete (2014)	Utilized approach	Employed F-AHP and FDM to evaluate of luxury resort hotels criteria
Rikhtegar et al. (2014)	Utilized approach	Applied F-SAW and ANP for assessment of risks pertaining in the mining projects
Azadnia et al. (2014)	Utilized approach	Employed F-AHP and RBWF methods for selection of sustainable supplier
Rabbani et al. (2014)	Utilized approach	Implemented of fuzzy COPRAS, ANP and SBSC for evaluation of performance in Iranian oil companies
Tadić et al. (2014)	Utilized approach	Utilized fuzzy ANP, fuzzy VIKOR and fuzzy DEMATEL for selection of city logistics
Zavadskas, Antucheviciene et al. (2014)	Approach developed	Developed WASPAS and results compared with COPRAS-IVIF-TOPSIS-IVIF and IFOWA for improve of WPM and WSM accuracy
Zavadskas, Turskis, and Bagočius (2014)	Utilized approach	Used ARAS-F and AHP for solve of problems in construction site selection in Eastern Baltic see
Avikal, Mishra et al. (2014)	Utilized approach	Applied F-AHP and PROMETHEE approaches for selection tasks in disassembly line
Akdag et al. (2014)	Utilized approach	Used fuzzy set, AHP, TOPSIS, OWA and Yager's min–max to evaluated of hospital service quality
Rabbani et al. (2014)	Utilized approach	Used ANP, COPRAS and BSC approaches for assessment of performance in oil companies
Kucukvar et al. (2014)	Utilized approach	Applied F-ENTROPY and TOPSIS for ranking of life cycle sustainability performance
Vinodh, Prasanna, and Hari Prakash (2014)	Utilized approach	Employed F-AHP and TOPSIS for selection and assessment of performance in plastic recycling
Yeh et al. (2014)	Utilized approach	Used F-AHP and F-DEMATEL for identifying the critical factors in NPD
Tavana, Khalili-Damghani, and Rahmatian (2014)	Utilized approach	Employed F-ANP, DEMATEL and F-DEA for evaluation of performance in pharmaceutical companies
Wang and Wu (2014)	Utilized approach	Applied F-AHP, F-DEMATEL and FDM for evaluation of PLC
Anojkumar et al. (2014)	Utilized approach	Employed FAHP-VIKOR, FAHP-PROMTHEE, FAHP-TOPSIS and FAHP-ELECTRE for selection of material in sugar industry
Zavadskas, Antucheviciene, Hajiagha, and Hashemi (2014)	Approach developed	Developed WASPAS-IVIF for evaluation of performance in MCDM problems
Hashemian et al. (2014)	Utilized approach	Applied F-AHP and F-PROMETHEE for assessment of supplier process
Ghorabaee et al. (2014)	Utilized approach	Used of F-COPRAS and interval type-2for selection of supplier
Moghimi and Anvari (2014)	Utilized approach	Employed F-AHP and TOPSIS for evaluating of performance in cements firms
Uygun, Kaçamak, and Kahraman (2014)	Utilized approach	Utilized F-ANP and DEMATEL for selecting and evaluating of outsourcing provider
Avikal, Jain et al. (2014)	Utilized approach	Implemented of F-AHP, M-TOPSIS and KANO model for ranking the tasks in work stations bade on their assignment
Liou, Chuang, and Tzeng (2014)	Utilized approach	Applied ANP and DEMATEL for improve and evaluate supplier
Safaei Ghadikolaei et al. (2014)	Utilized approach	Employed F-AHP, F-COPRAS, F-VIKOR, ARAS-F for performance evaluation in Iranian companies
Kabir and Sumi (2014)	Utilized approach	Utilized F-AHP and PROMETHEE for selection of TQM consultant
Baykasoglu and Durmusoglu (2014)	Utilized approach	Implemented of FCM, ANP and DEMATEL for evaluation of private school in the primary level
Bairagi et al. (2014)	Utilized approach	Employed F-AHP, F-VIKOR- F-TOPSIS and COPRAS-G for selection of robots
Keršulienė and Turskis (2014)	Utilized approach	Utilized ARAS-F and AHP for selection of chief officer in the accounting department
Zamani et al. (2014)	Utilized approach	Used ARAS-F and ANP for extension of brand in marketing strategies
Kaya and Kahraman (2014)	Utilized approach	Implemented of F-TOPSIS and F-AHP for performance evaluation of intelligent building
Yazdani-Chamzini (2014)	Utilized approach	Applied F-AHP and F-TOPSIS for selection and evaluation of the feasible handling equipment
İntepe, Bozdag, and Koc (2013)	Utilized approach	Applied MOLP and TOPSIS in order to determine assembly process
Sakthivel et al. (2013)	Utilized approach	Proposed TOPSIS, GRA and FAHP to assess the best fuel blend
Ghorbani, Mohammad Arabzad, and Shahin (2013)	Utilized approach	Employed FAHP and F-TOPSIS to selection of supplier based on F-Kano
Tavana, Zandi et al. (2013)	Utilized approach	Applied group FANP and TOPSIS to assess a community's overall e-government readiness
Samvedi, Jain, and Chan (2013)	Utilized approach	Integrated FAHP and F-TOPSIS for selection of risks in a supply chain
Jun, Chung, Kim, and Kim (2013)	Utilized approach	Using of TOPSIS, F-TOPSIS and WSM for determine the risks of flood in South Korea
Hsu, Liou, and Chuang (2013)	Approach developed	Combined ANP and DEMATEL methods for selection of outsourcing provider
Tavana, Khalili-Damghani, and Abtahi (2013)	Utilized approach	Application of ANP and F-TOPSIS for selection of location international distribution center
Baykasoğlu, Kaplanoğlu, Durmuşoğlu, and Şahin (2013)	Utilized approach	Integrating fuzzy hierarchical TOPSIS and F-DEMATEL for selection of truck
Dincer and Hacioglu (2013)	Utilized approach	Employed of F-VIKOR and F-AHP for satisfy of customer in Turkish banks
Vinodh, Varadharajan, and Subramanian (2013)	Utilized approach	Employed F-TOPSIS and VIKOR for best concept to enhance the agility in product design
Lin (2013)	Utilized approach	Utilized of FDM, FAHP for evaluation of fashion design scheme criteria
Kahraman, Suder, and Cebi (2013)	Utilized approach	Employed F-AHP and F-TOPSIS to evaluation of NPD performance
Ma et al. (2013)	Utilized approach	Integrated Delphi method and FAHP for selection of technology process
Sari (2013)	Utilized approach	Integrated F-TOPSIS, FAHP and Monte Carlo simulation for RFID selection
Liu, Wu, and Li (2013)	Utilized approach	Proposed OWA operator and VIKOR- for evaluation HCW disposal methods
Zouggari and Benyoucef (2012)	Utilized approach	Employed FAHP and F-TOPSIS for suppliers' selection
Kabak, Burmaoğlu, and Kazançoğlu (2012)	Utilized approach	Combined FANP, F-TOPSIS and F-ELECTRE sniper selection
Büyüközkan and Çifçi (2012)	Utilized approach	Combined F-DEMATEL, F-TOPSIS and F-ANP for supplier selection
Chou and Cheng (2012)	Utilized approach	Combined FANP and F-VIKOR for evaluation of website quality
Fouladgar, Yazdani-Chamzini, Lashgari et al. (2012)	Utilized approach	Employed FAHP and COPRAS for evaluation of maintenance strategy
Choudhary and Shankar (2012)	Utilized approach	Applied F-AHP-TOPSIS for selecting and evaluating of optimal locations in TTPs
Yalcin, Bayrakdaroglu, and Kahraman (2012)	Utilized approach	Using FAHP, TOPSIS and VIKOR for evaluation of financial performance

(*continued on next page*)

Table 9 (*continued*)

Authors	Type of study	Tools and approaches
Fouladgar, Yazdani-Chamzini, Zavadskas, and Haji Moini (2012)	Utilized approach	Employed F-ANP and fuzzy COPRAS for working evaluation strategies
Baležentis et al. (2012)	Utilized approach	Using F-VIKOR, F-TOPSIS, and F-ARAS for economic sectors assessment
Aliei et al. (2012)	Utilized approach	Using FAHP and F-TOPSIS for technology information assessment
Hsu, Wang, and Tzeng (2012)	Utilized approach	Combined DEMATEL and ANP with VIKOR to solve the recycled materials
Chou, Sun, and Yen (2012)	Utilized approach	Using FAHP and F-DEMATEL to evaluate Taiwanese universities performance
Chen and Chen (2012)	Utilized approach	Application F-DEMATEL, FANP and FAHP for TQM measurement criteria performance
Zeki Ayağ and Gürcan Özdemir (2012)	Utilized approach	Using ANP and modified TOPSIS for evaluation of machine tool alternatives
Taha and Rostam (2012)	Utilized approach	Employed FAHP and PROMETHEE to determine the weights of the criteria
Kutlu and Ekmekçioğlu (2012)	Utilized approach	Application of FAHP and F-TOPSIS for failure effects and modes
Paksoy, Pehlivan, and Kahraman (2012)	Utilized approach	Using FAHP and F-TOPSIS for development of organization strategy in distribution channel management
Demirel, Yücenur, Demirel, and Muşdal (2012)	Utilized approach	Using FAHP and FANP for the evaluation of alternate land cover policies
Büyüközkan and Çifçi (2012)	Utilized approach	Application of F-DEMATEL, F-TOPSIS and FANP to evaluate the green supplier
Atalay and Eraslan (2012)	Utilized approach	Applied FAHP, F-TOPSIS, and FADT for electronic devices evaluation
Büyüközkan, Arsenyan, and Ruan (2012)	Utilized approach	Applied FAHP and F-TOPSIS for determine weights of criteria for selecting logistics tool
Chen and Yang (2011)	Approach developed	Employed the F-TOPSIS and FAHP for supplier selection
Kuo (2011)	Approach developed	Developed F-DEMATEL and TOPSIS for selection of location in center of international distribution
Ka (2011)	Utilized approach	Applied F-ELECTRE and FAHP to selection of China dry port location
Tuzkaya, Gülsün, and Önsel (2011)	Utilized approach	Evaluation of MHESP by employ the FANP and F-PROMETHEE approaches
Deng and Chan (2011)	Approach developed	Combination of FST, TOPSIS and DST to deal with selection of supplier problem
Yu, Guo, Guo, and Huang (2011)	Utilized approach	Using AHP and F-TOPSIS for ranking of B2C e-commerce websites
Lashgari, Fouladgar, Yazdani-Chamzini, and Skibniewski (2011)	Utilized approach	Combined FAHP F-TOPSIS in order to select a proper shaft sinking method
Shafia, Mazdeh, Vahedi, and Pournader (2011)	Utilized approach	Used F-TOPSIS and SAW for evaluation of CRM performance based on BSC
Aydogan (2011)	Utilized approach	Integrated Rough-AHP and F-TOPSIS for ranking performance measurement in Turkish aviation firms
Liao (2011)	Utilized approach	Applied FAHP and MSGP for select the best pricing strategy for NPD
Shen, Lin, and Tzeng (2011)	Utilized approach	Integrated FDM, DEMATEL and ANP for construct a technology selection model
Rostamzadeh and Sofian (2011)	Utilized approach	Using of FAHP and F-TOPSIS for prioritization effective of 7Ms performance
Kaya and Kahraman (2011)	Utilized approach	Integrated F-VIKOR and FAHP for selection of alternative forestation areas in Istanbul
Hung (2011)	Utilized approach	Integrated DEMATEL, FGP and ANP for activity-based divergent supply chain
Hadi-Vencheh and Mohamadghasemi (2011)	Approach developed	Implemented of FAHP, DEA and SAW for classify of ABC inventory
Dalalah, Hayajneh, and Batieha (2011)	Utilized approach	Modified F-DEMATEL and TOPSIS for evaluation and selection supplier based on criteria
Pires, Chang, and Martinho (2011)	Utilized approach	Employed AHP based on F-TOPSIS for evaluation of solid waste management in Portugal
Kahraman and Kaya (2011)	Utilized approach	Using F-AHP and F-ELECTURE for evaluation of websites quality levels
Fu, Chu, Chao, Lee, and Liao (2011)	Utilized approach	Applied FAHP and VIKOR for evaluation performance in 26 international hotels
Azadeh, Nazari-Shirkouhi, Hatami-Shirkouhi, and Ansarinejad (2011)	Utilized approach	Combined FAHP and TOPSIS for productive operators' assignment
Rathod and Kanzaria (2011)	Utilized approach	Application AHP, TOPSIS and F-TOPSIS to solve PCM selection problem
Ekmekçioğlu, Kaya, and Kahraman (2010)	Utilized approach	Applied FAHP and modified F-TOPSIS for the selection of appropriate disposal method and site for MSW
Chen and Chen (2010)	Utilized approach	Applied FAHP and VIKOR to complete the construction of the AIS
Liou and Chuang (2010)	Utilized approach	Used FMCDM and FAHP for determine reputation and n corporate image criteria
Tuzkaya, Gülsün, Kahraman, and Özgen (2010)	Utilized approach	Implemented of F-ANP and F-PROMETHEE for evaluation of material handling equipment
Kaya (2010)	Utilized approach	Application of FAHP and F-TOPSIS- for website quality evaluation
Dursun and Karsak (2010)	Utilized approach	Using of F-TOPSIS and OWA operator for personnel selection
Wang, Fan, and Wang (2010)	Utilized approach	Integrated FAHP, TOPSIS and FPP methods for aero engine health assessment"
Önüt, Efendigil, and Soner Kara (2010)	Utilized approach	Combined FAHP and F-TOPSIS for selection the shopping center site
Chatterjee, Manikrao Athawale, and Chakraborty (2010)	Utilized approach	Using VIKOR and ELECTRE to solve the robot selection problems
Chen and Hung (2010)	Utilized approach	Using F-AHP and F-TOSIS for selection of partners' strategic manufacturing
Tsai et al. (2010)	Utilized approach	Employed FAHP and Delphi for evaluation of performance in hospital organization
Amiri (2010)	Utilized approach	Using F-TOPSIS and AHP to analyze the structure of the project selection problem
Chen and Wang (2010)	Utilized approach	Using FDM and FAHP for evaluation firms adjust business strategy
Sun (2010)	Utilized approach	Employed FAHP and FTOPSIS, for the evaluation of performance
Chen and Chen (2010)	Utilized approach	Applied VIKOR and FAHP for complete the construction of the AIS
Torfi, Farahani, and Rezapour (2010)	Proposed approach	Applied FTOPSIS and FAHP to determine the relative weights and rank the alternatives
Önüt, Kara, and Işik (2009)	Utilized approach	Developed a supplier evaluation approach based on the TOPSIS and ANP
Boran, Genç, Kurt, and Akay (2009)	Utilized approach	Combined F-TOPSIS and IFWA for select supplier in group decision making
Gumus (2009)	Utilized approach	Applied FAHP and TOPSIS for evolution of hazardous waste in transportation firms
Demirel, Muşdal, Demirel, and Yücenur (2009)	Utilized approach	Using FAHP and FANP for agricultural strategy selection
Bashiri and Hosseininezhad (2009)	Proposed approach	Employed of FAHP and FIS for multi-facility location problems
Ertuğrul and Karakaşoğlu (2009)	Utilized approach	Using FAHP and TOPSIS for evaluation of performance in Turkish cement firms
Wu, Tzeng, and Chen (2009)	Utilized approach	Using FAHP, TOPSIS, SAW and VIKOR for rank banking performance
Zaerpour, Rabbani, Gharehgozli, and Tavakkoli-Moghaddam (2009)	Utilized approach	Employed FAHP and TOPSIS for classify of make to stock, make to order and hybrid products
Mahdavi, Heidarzade, Sadeghpour-Gildeh, and Mahdavi-Amiri (2009)	Proposed approach	Defined FPIS and FNIS based of TOPSIS concept for decision making problems
Ilangkumaran and Kumanan (2009)	Utilized approach	Using of FAHP and F-TOPSIS for maintenance policy selection in textile industry
Büyüközkan and Ruan (2008)	Utilized approach	Presented the F-VIKOR and FMCDM for measuring of software development projects performance
Hsia, Chen, and Chen (2008)	Utilized approach	Proposed FAHP and FMCDM to determine the relative weights between each independent common factor

Table 9 (*continued*)

Authors	Type of study	Tools and approaches
Önüt, Kara, and Efendigil (2008)	Utilized approach	Application of FAHP and F-TOPSIS approaches for the selection of machine tools
Sheu (2008)	Utilized approach	Application of FAHP, FMCDM and TOPSIS in global logistics management
Lee et al. (2008)	Utilized approach	Implemented of FAHP and AHP for evaluation of hydrogen technology sector in Korea
Önüt and Soner (2008)	Utilized approach	Applied F-TOPSIS and FAHP to solve the solid waste transshipment site selection
Perçin (2008)	Utilized approach	Applied F-AHP, FTOPSIS for assessment of information sharing decision problems
Ertuğrul and Karakaşoğlu (2008)	Utilized approach	Applied FAHP and F-TOPSIS for selection of facility location
Gharehgozli, Rabbani, Zaerpour, and Razmi (2008)	Utilized approach	Employed TOPSIS and AHP for manufacturing system capacity
Kwok, Zhou, Zhang, and Ma (2007)	Approach developed	Using of fuzzy OWA operator and AHP for selection of students IS group projects
Bilsel, Büyüközkan, and Ruan (2006)	Utilized approach	Using AHP and F-PROMETHEE for determine the weights of hospital Web sites
Tesfamariam and Sadiq (2006)	Utilized approach	Used FAHP and AHP for vagueness type uncertainty in risk environments
Chen and Tzeng (2004)	Approach developed	Applied FAHP and FTOPSIS for selection expatriate host country
Tsaur, Chang, and Yen (2002)	Utilized approach	Using FAHP and F-TOPSIS for performance evaluation of three airline service quality

Table 10
Author Distribution by Nationality.

No.	Country	Frequency	Percent (%)	No.	Country	Frequency	Percent (%)
1	Taiwan	232	21.46	31	Tunisia	4	0.37
2	Turkey	132	12.21	32	Saudi Arabia	3	0.28
3	Iran	121	11.19	33	Montenegro	3	0.28
4	China	116	10.73	34	Singapore	3	0.28
5	India	74	6.85	35	Jordan	2	0.19
6	USA	46	4.26	36	Oman	2	0.19
7	Republic of Korea	33	3.05	37	Denmark	2	0.19
8	UK	32	2.96	38	Slovenia	2	0.19
9	Italy	27	2.50	39	Kuwait	2	0.19
10	Lithuania	22	2.04	40	Chile	2	0.19
11	Canada	22	2.04	41	Bosnia and Herzegovina	1	0.09
12	Spain	20	1.85	42	Hungary	1	0.09
13	Australia	17	1.57	43	Austria	1	0.09
14	Malaysia	18	1.67	44	Israel	1	0.09
15	Greece	14	1.30	45	Romania	1	0.09
16	Hong Kong	12	1.11	46	Cuba	1	0.09
17	France	12	1.11	47	Indonesia	1	0.09
18	Poland	11	1.02	48	Yugoslavia	1	0.09
19	Finland	10	0.93	49	Sweden	1	0.09
20	Portugal	9	0.83	50	Norway	1	0.09
21	Japan	7	0.65	51	Pakistan	1	0.09
22	Germany	7	0.65	52	New Zealand	1	0.09
23	Netherlands	7	0.65	53	Bangladesh	1	0.09
24	South Africa	6	0.56	54	Cyprus	1	0.09
25	Belgium	6	0.56	55	Morocco	1	0.09
26	Serbia	6	0.56	56	Algeria	1	0.09
27	Brazil	5	0.46	57	Ireland	1	0.09
28	Mexico	5	0.46	58	Argentina	1	0.09
29	Egypt	4	0.37	59	Philippines	1	0.09
30	Thailand	4	0.37				

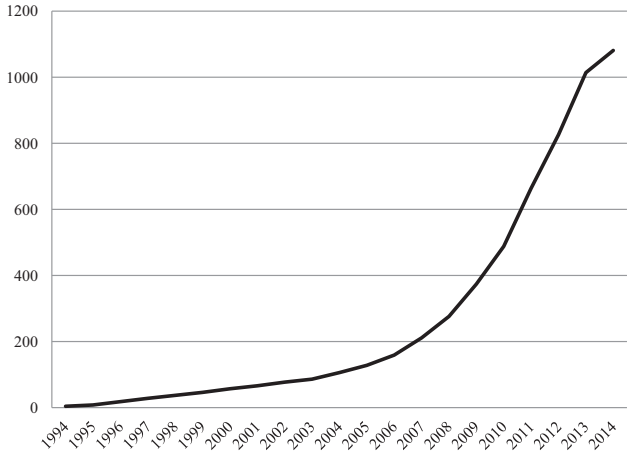

Fig. 2. Distribution of publications year.

with other methods, 11 papers have employed ELECTRE and combined it with other methods, 13 papers have employed DEMATEL and combined it with other methods, 10 papers have employed PROMETHEE and combined it with other methods, and 32 papers have employed other combined tools and approaches such as ARAS, WASPAS. In the category of tools and application, researchers in management and business fields have applied 45 papers fuzzy TOPSIS and mixed it with other methods, 64 papers have used fuzzy AHP and mixed it with other methods, 15 papers have used fuzzy ANP and mixed it with other methods, 13 papers have used fuzzy VIKOR and mixed it with other methods, six papers have used fuzzy DEMATEL and mixed it with other methods, and 15 papers have used other mixed tools and applications such as ARAS-F, F-ELECTRE, F-COPRAS and so on. In case of the implementation of tools and applications in this category, 15 cases have utilized fuzzy TOPSIS and integrated it with other methods, 32 cases have utilized fuzzy AHP and integrated it with other methods; eight papers have utilized fuzzy DEMATEL and integrated it with other methods, five studies have utilized fuzzy VIKOR and

integrated it with other methods. Question five was; which countries have published these fuzzy MCDM tools based on the number of publications in these four fields? The results related to this question were shown in Table 1). According to this table, the most contributing countries are Taiwan (21.46%), Turkey (12.21%), Iran (11.19%) and China (10.73%). The results for the last question were presented in Table 10. Question six was; which year authors have further published fuzzy MCDM tools based on frequency in the four fields? Accordingly, it can be indicated that, the use of these tools and approaches in 1994 was four papers and this number increased to 10 papers in 1996. Surprisingly, from 2008 to 2009, the numbers of studies have dramatically increased. Although the use of fuzzy MCDM and MCDM tools and approaches have increased in each year, the number of those papers in 2012 (171) have decreased compared to 2011 (176). Another interesting result in this table is about 2013 which previous studies have applied tools and techniques more than other years. This year has the highest number of publications (188).

6. Conclusion

In decision-making fuzzy applications and theories, different modeling techniques have been offered, a number of suitable approaches have been provided for modeling decision aiding, 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 decision making, desired goals, available information, time, and so on. A number of branches of the fuzzy decision theory have departed from the stand expected utility paradigm. The most important advantage of the fuzzy 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 are not possible to be solved by the use of common optimization models. This review paper is mainly focused on the overview of the utilization of fuzzy decision support tools, e.g., recent developments of fuzzy models of multicriteria decision analysis. These tools 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 systematically review of FMCDM which classify papers in four difference main fields including engineering, science, technology and science. Several significant papers in FMCDM issues are introduced by this paper.

In this paper, the literature was reviewed for the classification and interpretation of the emerging issues that make use of the FMCDM methodology. In the present review, a total of 413 papers were collected from 150 journals, published since 1994, and they were categorized into four main fields. The papers were classified based on the journal's name, publication year, authors' nationality, application areas, and other combined FMCDM methods. This paper contributed to the development of a classification scheme focusing on practical considerations, reviewing structurally the literature to create a guide for further studies on the FMCDM methods, and the identification of issues for future studies. Additionally, in our study, two new perspectives are taken into consideration to review the articles, namely categorization of the articles into four main fields (business, science, engineering, and technology) and examination of the type of study (FMCDM utilizing research, FMCDM developing research and FMCDM proposing research).

Generally, the FMCDM 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 emphasized. Future study on the fuzzy MCDM anatomy can be further developed. In this study, a number of techniques have been studied as fuzzy individual techniques and they are integrated or combined with other techniques; however, many other conventional MCDM techniques have not been studied. Another recommendation for future research is the investigation on the distinct differences and similarities among fuzzy MCDM methods. The insights that were provided in the present review help channel research efforts and fulfill practitioners' and researchers' requirements for an easy reference to fuzzy 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 fuzzy DM techniques. Articles published in late 2014, if any, are not included in the present paper due to the limitation of reporting time. A future review can be expanded further in scope. In addition; our paper more focuses on four main fields of engineering, management and business, science and technology. In this regard, future studies can use this paper for classify based on different sub-fields and sub-areas. Another limitation is that the data were collected from journals, not including papers conference papers, textbooks, doctoral and master dissertations and thesis and unpublished papers in the FMCDM issues. As a result, in a future study, 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 papers were found on English language journals; then, the scholarly journals in the other languages were not involved in our review paper. It may mean that our paper is not complete; however, we believe that our paper comprehensively reviews and includes most of the papers presented by high-ranking journals. As a result, our review paper can provides a better understanding of FMCDM methods for future academic scholars. This study is hoped to be employed by academics and managers as a basis for further research, help practitioners make more appropriate decisions using these techniques, and guide scholars to enhance these methodologies. This paper selected and summarized carefully those papers that were available in some available 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 papers which did not mentioned in this review paper.

Recently, development of hybrid and modular methods is becoming increasingly important. They are based on previously developed well-known methods, such as FTOPSIS, FSAW, FDEA, FAHP, FANP, FVIKOR, FDEMATEL, FDEA, FPROMETHEE, FELECTRE and their modification, by applying fuzzy and gray 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 FMCDM techniques and applications of hybrid FMCDM methods, it is necessary to publish reviews on these issues in future. As another limitation the paper presents synopsis of numerous publications, which describe the use of FMCDM methods in journals and some of the relatively recently developed methods. However, this review does not cover recent methods that have not yet been reviewed in books.

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