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Review

Survey on fuzzy TOPSIS state-of-the-art between 2007 and 2017

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A crucial topic in expert system and operations research is fuzzy multi-criteria decision making (FMCDM), which is used in different fields. Existing options and gaps in this topic must be understood to prepare valuable knowledge on FMCDM environments and assist scholars. This study maps the research landscape to provide a clear taxonomy. The authors focus on searching for articles related to (i) technique for order of preference by similarity to ideal solution (TOPSIS); (ii) development; and (iii) fuzzy sets in four primary databases, namely, IEEE Xplore, Web of Science, Elsevier ScienceDirect and Springer. These databases include literature that focuses on FMCDM. The resulting final set after the filtering process includes 170 articles, which are classified into four categories. The first, second, third and fourth categories include articles that used a type-1 fuzzy set with the TOPSIS method, a type-2 fuzzy set with the TOPSIS method, two fuzzy membership functions and a survey paper, respectively. The basic attributes of this topic include motivations for utilising FMCDM, open challenges and limitations that obstruct utilisation and recommendations to researchers for increasing the approval and application of FMCDM.

1. Introduction

Fuzzy multi-criteria decision making (MCDM) (FMCDM), which contains numerous decision alternatives and criteria, is a crucial topic in expert system and operation research. MCDM aims to identify the most eligible alternative(s) from a set of alternatives on the basis of the selected criteria. MCDM techniques can solve a wide range of engineering, economics, management and social problems (Vahdani et al., 2011a; Park et al., 2011; Vahdani et al., 2013; Singh and Benyoucef, 2011; Javadian et al., 2009; Aghaie et al., 2011; Abd et al., 2014). MCDM can also be used to solve problems in many other fields, such as medicine, sports science, networking and communication (Liu and Chang, 2010; Feng et al., 2016; Xing et al., 2009; Li and Zhang, 2009; Baykasoğlu and Gölcük, 2015; Xu and Zhang, 2013). Various techniques are used to solve problems in MCDM. MCDM has two approaches: (1) the human approach, such as analytic hierarchy process (AHP) and best–worst method (BWM). This approach depends on human preferences; and (2) the mathematical approach, which depends on mathematical operations, such as technique for order of preference by similarity to ideal solution (TOPSIS) and simple additive weighting (SAW). TOPSIS is the most popular method used in the mathematical approach. Its core idea is to select the optimal solution by simultaneously measuring the distances of each alternative to positive (PIS) and negative ideal solutions (NIS). PIS is an alternative and is the most preferred solution by decision makers (DMs) in maximising benefit criteria and minimising cost criteria, whereas NIS is the least preferred solution in maximising cost criteria and minimising benefit criteria. The preference order is subsequently constructed in accordance with the alternative that is closest to the PIS and farthest from the NIS, thereby resulting in a scalar criterion that combines the two distance measures and the optimal alternative (Roszkowska and Wachowicz, 2015). The steps of fuzzy TOPSIS (FTOPSIS) are presented as follows:

Step 1: The decision matrix is created.
Step 2: The weight of the criteria is computed using various techniques, such as AHP and BWM, based on the human approach or entropy that depends on mathematical operations.
Step 3: The normalised decision matrix is computed.
Step 4: The weighted normalised fuzzy decision matrix is computed.
Step 5: The fuzzy PIS (FPIS) and fuzzy NIS (FNIS) are computed.
Step 6: The distance to the FPIS and FNIS from each alternative is computed.
Step 7: The closeness coefficient CCi for each alternative is computed.
Step 8: The alternatives are ranked as follows: The alternative with the highest closeness coefficient represents the optimal alternative (Nădăban et al., 2016).

However, TOPSIS has encountered many problems, such as the type of normalisation technique, its effect on data and its effect

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on the final selection. In addition, the distance measurement that uses TOPSIS involves various techniques for measuring the distance between PIS and NIS, and each technique provides different results. In general, MCDM techniques contain DM preferences and subjective judgments, including quantitative and/or qualitative criteria ratings, in addition to the weights of criteria. However, these issues can be imprecise, indefinite and uncertain, thereby complicating the decision-making process when applied to real-world problems (Vahdani et al., 2011a). Real number is not constantly suitable for solving real-life problems, especially when the problem requires subjective judgments (Krohling and Campanharo, 2011; Chamodrakas et al., 2011; Cheng and Lin, 2012; Javadian et al., 2009; Wan et al., 2016c; Yaakob et al., 2015). Fuzzy set theory, which is introduced by Zadeh, can handle subjective judgments (Singh and Benyoucef, 2011; Krohling and Campanharo, 2011; Vahdani et al., 2013; Li et al., 2009; Wang et al., 2007).

This paper aims to provide beneficial insights into decision-making processes under a fuzzy environment and assist scholars in understanding existing techniques to fill in the gaps of the topic and present a coherent taxonomy for the literature. Moreover, the benefits and challenges of the topic are determined. This paper is organised as follows. Section 1 introduces the MCDM and TOPSIS methods. Section 2 describes the research process, scope, literature sources and filtering steps. Section 3 presents the results of the final set of articles in this paper and creates a taxonomy for related literature and statistical information. Section 4 classifies and discusses the benefits, challenges and recommendations extracted from the final set of articles on the MCDM from 2007 to 2017. Section 5 provides the conclusions.

2. Method

The keyword used in this study was 'FTOPSIS', which excludes all algorithms used in the MCDM. The scope of this study was limited by selecting only English literature and research, review and short survey articles. Furthermore, the search was limited to articles published in the last 10 years (2007–2017). In the real world, the most important databases are Web of Science (WoS), Elsevier ScienceDirect, IEEE and Springer. We searched for our articles from these databases.

In a systematic review, inclusion criteria are created to narrow down from general to specific topics.

2.1. Information sources

Three significant digital databases that focused on the search for targeted papers were used in this systematic review.

i. ScienceDirect is a digital database provides access to many important journals in decision-making and expert systems.
ii. IEEE Xplore is a digital library in technology and engineering.
iii. WoS indexes cross and multidisciplinary studies of pure and social sciences.
iv. Springer is a global scientific, technical and medical portfolio that provides researchers in academia, scientific institutions and corporate research and development (R&D) departments with quality content through innovative information, products and services.

The logic behind this selection is to collect the most essential articles that discuss the topic and cover the most specialised articles to conduct a systematic review.

2.2. Study selection

The study selection process consisted of searches in the three digital databases and screening and filtering processes. The initial filter was conducted by scanning the title and abstract and downloading articles that include the keyword 'TOPSIS' under a fuzzy environment. After extracting the articles from the first filter, the second filter focused on improving FTOPSIS only. The full text of each article was read, and irrelevant articles were excluded.

2.3. Search

The search commenced on the first week of April 2017 using the 'advanced search' in IEEE Xplore and ScienceDirect databases. We used a mix of keywords that included 'TOPSIS' or 'technique for order preference by similarity ideal solution' and development. The first study that used the keyword 'without fuzzy' is presented in Table 1**.** To exclude books and reports, the authors also applied the operation in each digital database and included journals and conference articles, which articles are the most appropriate types of papers for publishing the latest research that specialises in this field. The search in the WoS database started on July 6, 2017, and only English articles were selected. The search in Springer started on the first week of August 2018.

The second study that used the keywords 'TOPSIS' or 'technique for order preference by similarity ideal solution', 'development' and 'fuzzy' is summarised in Table 2.

The results in IEEE Xplore were similar in both cases. In ScienceDirect, only five new articles were downloaded using the second query. In WoS, the first query gathered all the articles in the second query.

2.4. Inclusion criteria

Every article that satisfied the required criteria (Fig. 1) was included. An article on the MCDM algorithms was classified into categories to build a taxonomy for our topic. After the two initial filters, we proposed several established acceptance criteria and excluded others. Articles that did not satisfy these criteria were excluded. The exclusion criteria include the following details: (1) The article is written in another language (non-English language). (2) The article focuses on a specific part of decision making rather than the development of FTOPSIS. (3) FTOPSIS was used only to extract the ranking (FTOPSIS is applied directly). (4) Any method with FTOPSIS was used. The same exclusion criteria are used in the preview content option for the Springer database.

3. Results and statistical information

The result of the first query search obtained 3072 articles: 1799 articles from Elsevier ScienceDirect, 730 articles from IEEE, 363 articles from WoS and 180 articles from Springer. The search was conducted from 2007 to 2017. After the first filter (scanning the titles and abstracts) and the second filter (focus on the FTOPSIS only) were simultaneously applied, the results included 399 articles and excluded 2493 papers. After the third filter (focus on the articles that discuss a specific improvement on the FTOPSIS only) was applied, the results included 187 articles and excluded 232 papers. Only 8 articles were duplicated in the 3 digital databases. After full-text reading of all the articles, 8 duplicate articles were excluded and 171 articles remained. The final set included 170 articles because no information could be obtained from 1 article in the WoS. These articles were read with the major aim of identifying a comprehensive map for the final set of papers. The result indicated that most of the articles (84.11%; 143/170) used type-1 fuzzy set, whereas several articles used type-2 fuzzy set (6.46%; 11/170). Certain articles did not explain the membership function (8.23%; 14/170). A survey article represents the ratio (1.17%; 2/170). Moreover, the authors found that these patterns captured the major categories of related studies, which were then classified into

Table 1
Query without using the word FUZZY.

Database	Query	No. of articles
IEEE	('Abstract': TOPSIS OR 'Abstract': 'technique for order preference by similarity ideal solution' AND 'Abstract': development)	730
Science Direct	(TOPSIS OR 'technique for order preference by similarity ideal solution') AND development	1799
WoS	TS = (TOPSIS OR 'technique for order preference by similarity ideal solution') AND TS = development	363

Table 2
Query using the word FUZZY.

Database	Query	No. articles
IEEE	('Abstract': TOPSIS OR 'Abstract': 'technique for order preference by similarity ideal solution' AND 'Abstract': development AND 'Abstract': Fuzzy)	730
Science Direct	(TOPSIS OR 'technique for order preference by similarity ideal solution') AND development AND fuzzy	1392
WoS	TS = (TOPSIS OR 'technique for order preference by similarity ideal solution') AND TS = development AND TS = fuzzy	196
Springer	TOPSIS AND development AND fuzzy	180

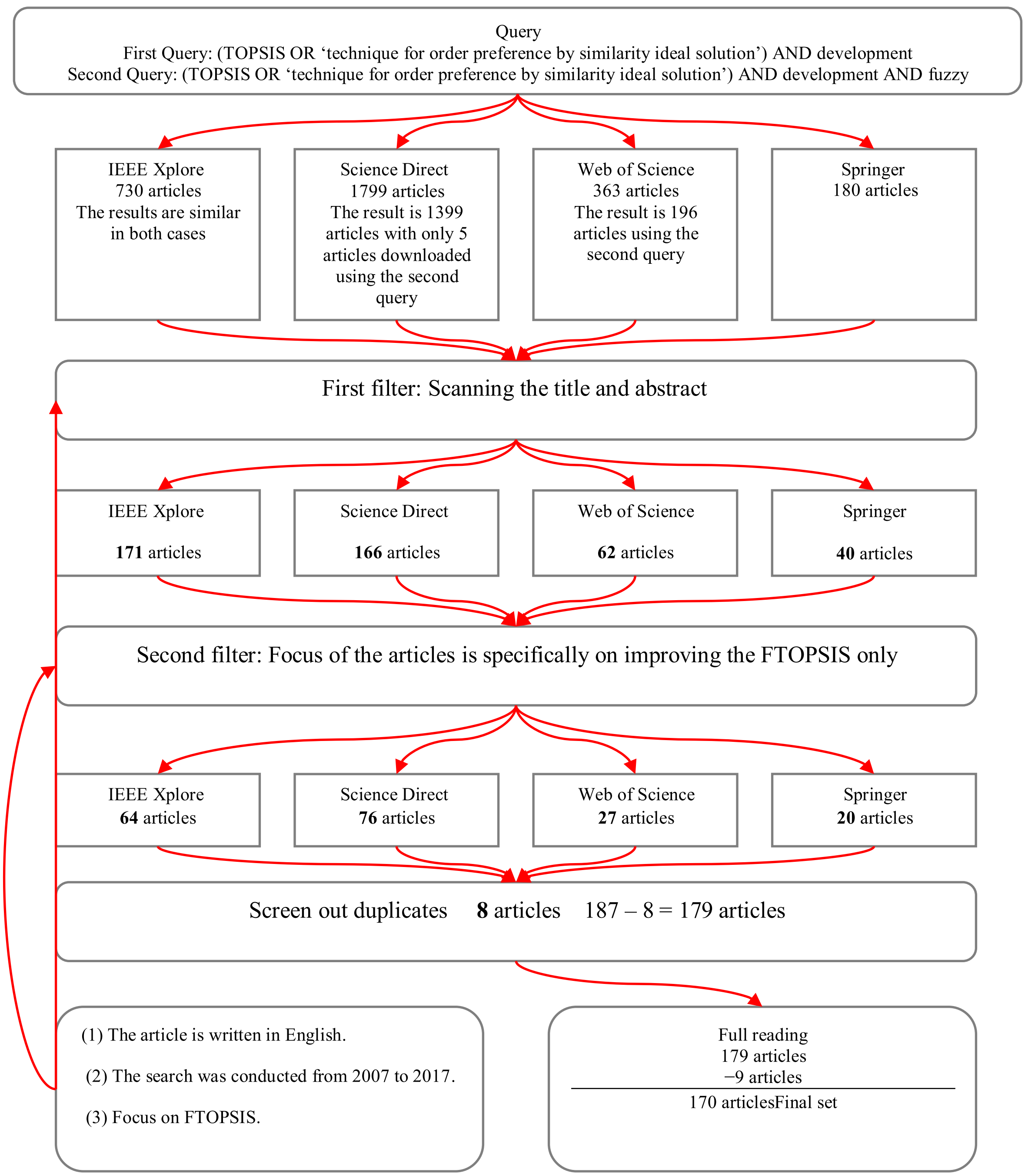


Fig. 1. Flowchart of the search query and inclusion criteria and the filtering process.

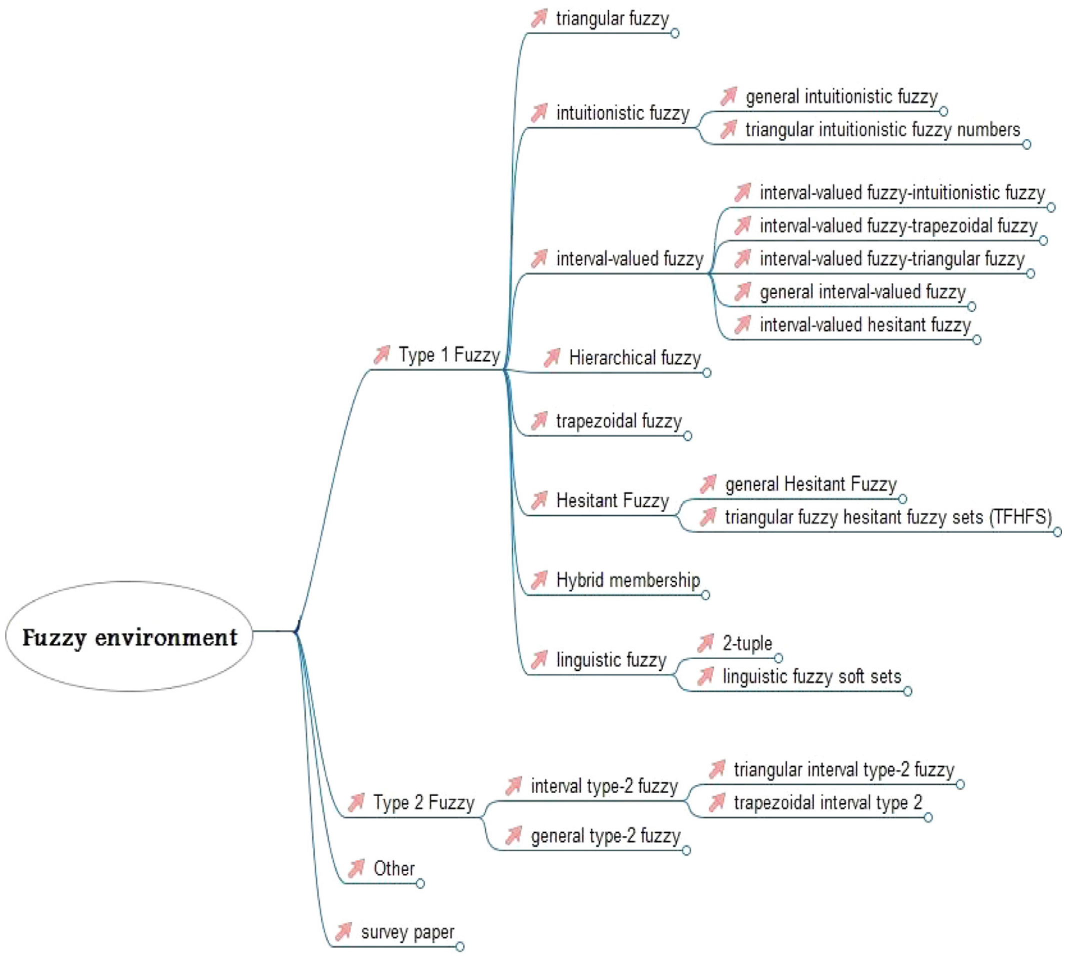


Fig. 2. Taxonomy of the research literature.

the categories of literature taxonomy (Fig. 2). Several subcategories could be divided into each main category. The taxonomy was created based on the fuzzy types, and the membership function was used in each article. In the next section, the categories and certain statistics from the final set of articles are presented.

3.1. Type-1 fuzzy set

Uncertainty and lack of information are the most important reasons that lead researchers to use the fuzzy set in the MCDM. In this branch, all the articles that used the type-1 fuzzy set were included. In fuzzy sets, each element is mapped to [0,1] by using a membership function. μA: X $\rightarrow$[0, 1], [0,1] are real numbers between 0 and 1 (including 0 and 1). Many membership functions are available. The final set of papers distributed depends on the membership function.

Most researchers used the type-1 fuzzy set. We classify all the articles of the type-1 fuzzy set into the following categories: The largest and easiest membership functions used in the type-1 fuzzy set are triangular fuzzy membership function (46.15%; 66/143). This research has been published in ScienceDirect (21 papers), WoS (11 papers), IEEE (26 papers) and Springer (8 papers). Then, researchers used triangular membership to solve various problems, including robot selection, rapid prototyping selection (Vahdani et al., 2011a), project rankings for participatory budget project (Walczak and Rutkowska, 2017), new product development (NPD) (Özdemir et al., 2010), flood vulnerability assessment (Lee et al., 2014), competitiveness of tourism industries in Asian countries (Huang and Peng, 2012), vessel selection (Yang et al., 2011), accidents with oil spill in the sea (Krohling and Campanharo, 2011), heterogeneous networks (Feng et al., 2016; Chamodrakas and Martakos, 2012b), service provider selection (Chamodrakas et al., 2011), e-sourcing (Singh and Benyoucef, 2011), personnel selection (Kelemenis and Askounis, 2010; Perez et al., 2012; Kelemenis and Askounis, 2009), customer evaluation (Chamodrakas et al., 2009), software outsourcing problem (Wang and Lee, 2009), green product development (Wang et al., 2015), configuration management (Chang and Tseng, 2008), water management (Sadr et al., 2015; Minatour et al., 2015), pancreatic islet transplantation (La Scalia et al., 2011), critical path (CP) definition (Zammori et al., 2009), dean selection in a university and identification of the most competitive port of the Bohai Bay in China (Fan and Feng, 2009), quality of service in the hotel industry (Benitez et al., 2007), missile weapon system selection (Li et al., 2010; Yang et al., 2014), prioritising barriers to green manufacturing (GM) (Mittal and Sangwan, 2014), optimum air-conditioning system selection for libraries (Xu and Chen, 2007), engine block and intake manifold (Yang et al., 2017), general example (Madi et al., 2015; Tian et al., 2010; Wei and Shengbao, 2008; Ran et al., 2008), e-commerce (Mao et al., 2015; Duan et al., 2010), new information system selection (Wang et al., 2007), new fuzzy positive and negative ideal solution (Javadian et al., 2009), supplier selection (Kar et al., 2014; Xie et al., 2016; Lima et al., 2013; Feng, 2012), transformer dissolved gas analysis (Guo-wei et al., 2009), young and promising doctoral researcher selection (Aghaie et al., 2011),

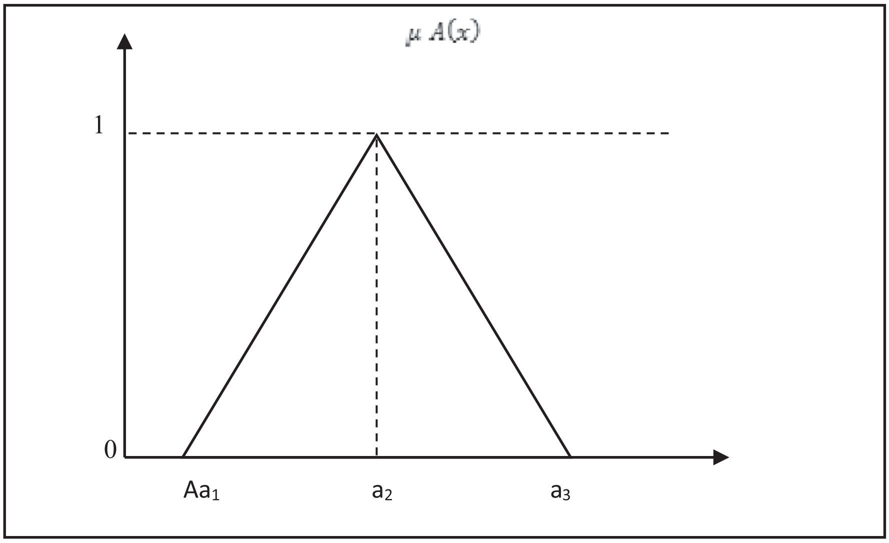


Fig. 3. Triangular membership.

automobile engine manufacturing (Pei and Zheng, 2010), enterprise resource planning (Lingyu et al., 2009), maintenance problem (Cables et al., 2012), competitive strategies on Turkish container ports (Celik et al., 2009), contractor prequalification evaluation process (Cui and Yang, 2009), information system project selection (Gao et al., 2008), support manager selection (Kelemenis et al., 2011), location selection (Zhou et al., 2012), human resource selection (Polychroniou and Giannikos, 2009), supplier ranking (Bandyopadhyay, 2016), ill-structured negotiation (Roszkowska and Wachowicz, 2015), construction project (Huang et al., 2010), supply chain (SC) risk evaluation (Zhang, 2008), reuse of industrial buildings in Hong Kong (Tan et al., 2014), evaluation of IT project risk (Xing et al., 2009), project selection problem (Fu, 2008; Yeh et al., 2009), life cycle costs (White and Chandrasekar, 2017), patient safety management (Wang and Chou, 2015), fragile state selection (Afful-Dadzie et al., 2015), network selection (Chamodrakas and Martakos, 2012a), location distribution centre selection in China (Chou and Chang, 2009) and partner selection of cooperation innovation alliance (Li, 2013). Fig. 3 shows the triangular membership function.

The second largest branch is intuitionistic fuzzy, which is a fuzzy extension of the type-1 fuzzy set. This type has been used in research 15.38% of the time (22/143). The research has been published in ScienceDirect (9 papers), WoS (3 papers), IEEE (9 papers) and Springer (1 paper). The concept of this type is to compute membership and non-membership. Two of these articles used triangular intuitionistic fuzzy to solve MCDM problems, such as selection difficulty (Wan et al., 2016a); another study used triangular intuitionistic fuzzy to solve a scientific journal evaluation (Li and Zhao, 2014). Other papers generally used intuitionistic fuzzy to solve different MCDM problems. These papers did not mention membership but instead mentioned the use of intuitionistic fuzzy. These papers include US wind energy (Gumus et al., 2016), supplier selection problem (Yue and Jia, 2015; Solanki et al., 2016; Guo et al., 2010; Ervural et al., 2015; Wood, 2016), outsourcing provider selection (Wan et al., 2015), problems with a battery industry involved in reutilising process (Su et al., 2011), evaluation problem for horizontal directional drilling machine (Geng et al., 2010), general example (Li et al., 2009), RFID technology selection (Wan et al., 2016b), heating device manufacturing in China (Pei, 2015), project risk evaluation (Guo and Zhang, 2009), project manager selection (Chen et al., 2016), problem evaluation in colleges (Li and Zhang, 2009), structured selection of partners in open innovation (OI) (Aloini et al., 2016), mobile phone selection (Büyüközkan and Güleryüz, 2015), township development (Mishra, 2016), impact of criterion weight techniques (Dammak et al., 2015) and failure detection (Aikhuele and Turan, 2016). Fig. 4 shows the intuitionistic membership function.

Furthermore, the articles used interval-valued fuzzy sets (IVFSs), which were placed in another branch based on the observation that numerous studies used IVFSs (12.58%; 18/143). IVFSs are classified into five subcategories. The first subcategory is interval-valued intuitionistic fuzzy set (IFS). This subcategory includes nine papers that used interval-valued IFS to solve different MCDM problems, such as project manager selection (Joshi and Kumar, 2016), optimum air-conditioning system selection for libraries (Park et al., 2011), supplier selection (Wan et al., 2016c; Yue, 2016; Wang et al., 2011; Xiao and Wei, 2008; Yadav and Kumar, 2009), general example (Wang and Xu, 2010) and selection problem (Chu and Liu, 2014). The second subcategory contains one research that used the interval-valued trapezoidal fuzzy membership to solve robot selection (Rashid et al., 2014). The third subcategory includes three papers that used interval-valued triangular membership function to solve the following problems: Location selection (Mokhtarian et al., 2014), robot selection (Vahdani et al., 2013) and general example (Run-qi, 2008). The fourth subcategory includes one research that used hesitant fuzzy with the IVFS to solve the energy policy selection problem (Xu and Zhang, 2013). The last subcategory includes four articles that used IVFS only to solve the supplier selection problem (Chen, 2011), general example (Rong and FAN, 2009), assess higher vocational education development levels (Li et al., 2016) and overseas oil–gas project (Huang et al., 2015). The other category in the type-1 fuzzy set is hierarchical fuzzy. This category contains four articles that used hierarchical fuzzy only, and the representative ratio of these articles is 2.79% (4/143). These articles solve MCDM problems, such as road safety evaluation (Bao et al., 2012), the strategy selection problem (Baykasoğlu and Gölcük, 2015), new product introduction (Kahraman et al., 2007) and product design evaluation (Wang and Chan, 2013). Fig. 5 shows the IVFS (A (a) = [x1, x2]) membership function.

A common membership function used the type-1 fuzzy set as a trapezoidal membership function, with 21 articles. These articles were published in ScienceDirect (9 papers), WoS (2 papers), IEEE (9 papers) and Springer (1 paper). The representative ratio of these articles is 14.68% (21/143). These

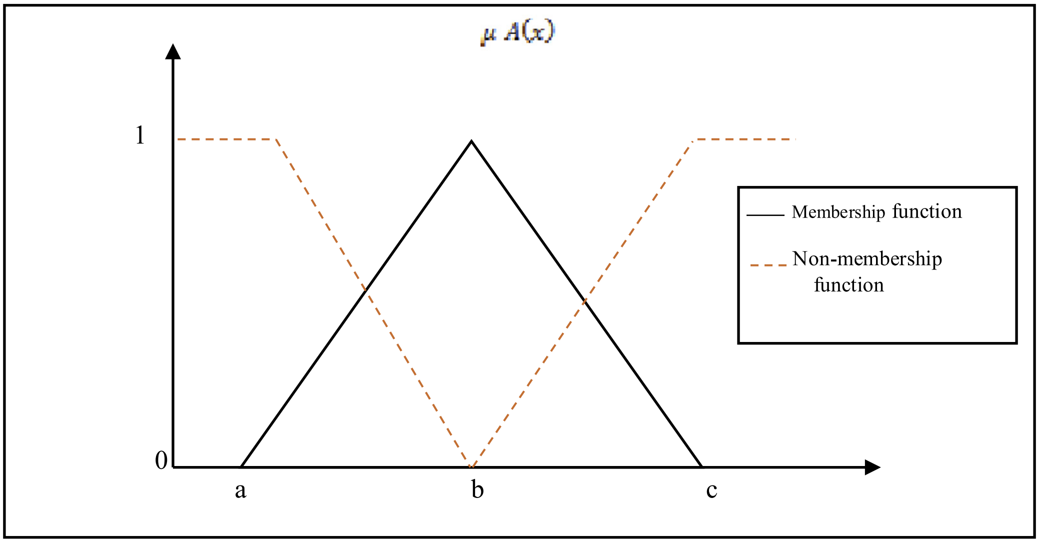


Fig. 4. Intuitionistic membership function.

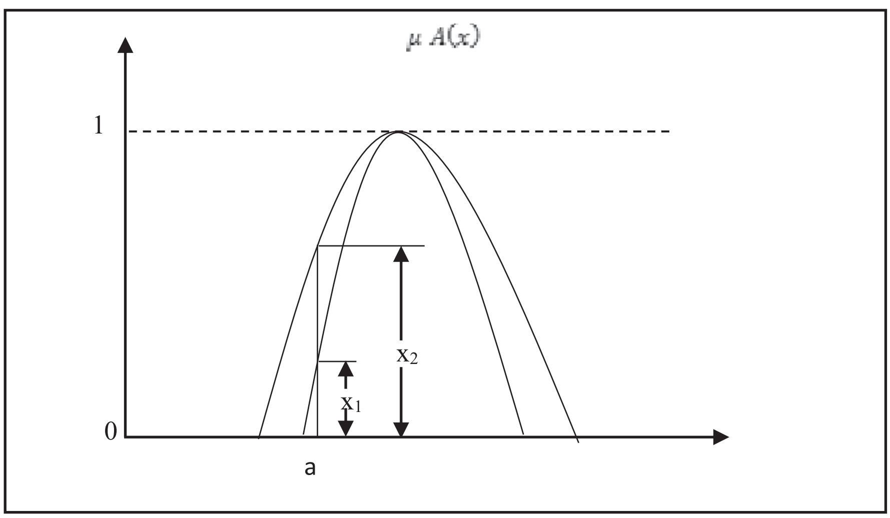


Fig. 5. IVFS (A (a) = [x1, x2]).

studies solve MCDM problems, such as the Tehran stock exchange (Hatami-Marbini and Kangi, 2017), credit limit allocation model for banks (İç, 2012), general example (Jiang et al., 2011; Haleh et al., 2010; Yuxun, 2010; Wang and Qin, 2008), supplier selection (Liao and Kao, 2011; Igoulalene et al., 2015; Bai et al., 2014), power planning in ICT infrastructure (Li and Chou, 2014), performance evaluation of technological innovation capabilities (Cheng and Lin, 2012), the largest producers of solar panels in Canada (Hatami-Marbini et al., 2013), fuel bus selection (Vahdani et al., 2011b), R&D projects (Collan et al., 2015; Collan and Luukka, 2014), portfolio optimisation model (Yang and Liu, 2016), new food product development (Chen and Niou, 2011), the selection problem (Yaakob and Gegov, 2015; Yaakob et al., 2016), supplier evaluation (Niyigena et al., 2012) and sustainable material selection (Vinodh and Girubha, 2013). Fig. 6 shows the trapezoidal membership function.

Another category is hesitant fuzzy set, which is a type of extension of the type-1 fuzzy set. Two papers used this category. A paper used the hesitant fuzzy set only to solve weapon selection problem (Wang et al., 2014), and another paper used triangular fuzzy hesitant fuzzy sets to solve hospital site selection (Senvar et al., 2016). The representative ratio of these articles is 1.39% (2/143). Several articles are placed under the linguistic fuzzy category, which can be classified into two subcategories. The three papers in the first subcategory used two tuples to solve supplier selection (Hu et al., 2015), the second paper solved location selection (Rao et al., 2015) and the third article has extended FMCDM to the evaluation processes (Espinilla et al., 2012). The second subcategory in linguistic fuzzy includes one paper that used linguistic fuzzy with soft sets to solve the selection of a feasible candidate and the assessment of sound quality problems (Tao et al., 2015). The representative ratio of these articles is 2.79% (4/143). The final category in the type-1 fuzzy set was placed under hybrid fuzzy membership. This category includes six articles that used two memberships in the same article. These articles conducted their experiments using two memberships to demonstrate suitability with different memberships or to illustrate the differences between the results when using each membership function. The articles solved different FMCDM problems, such as project selection (Khalili-Damghani and Sadi-Nezhad, 2013b, 2013a), supplier evaluation (Osiro et al., 2014), hierarchical medical system (Gou et al., 2017), scheduling problems in robotic flexible assembly

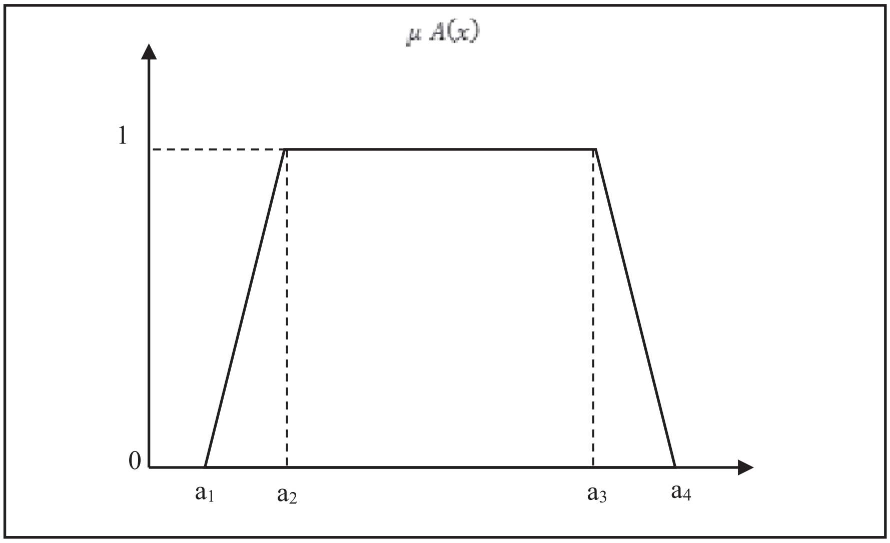


Fig. 6. Trapezoidal membership.

cells (Abd et al., 2014) and selection problem for commercial off-the-shelf (COTS) products (Mehlawat and Gupta, 2015). The representative ratio of these articles is 4.19% (6/143).

3.2. Type-2 fuzzy set

This category contains all the articles that used type-2 fuzzy set, which is the popularised type-1 fuzzy set that can function with uncertainty. Type-2 fuzzy set indicates that the value of the membership degree may include uncertainty. If the value of membership function is given by a fuzzy set, then this value is called the type-2 fuzzy set. This concept can be used to extend the fuzzy set into the type-n fuzzy set. It integrates the uncertainty of the membership function into fuzzy set theory and solves the problems of type-1 fuzzy sets. Several authors preferred using type-2 fuzzy set, with 11/170 (6.47%) of papers included in this category. These articles can be classified into two categories. The first category uses the type-2 fuzzy set only to solve the selection of an optimum portfolio of project problem (Khalili-Damghani et al., 2013). This category includes one paper only, and the representative ratio of this paper is 9.09% (1/11). The second category is called the interval type-2 fuzzy set and includes 10 papers. This category is further classified into two subcategories. The first subcategory is the interval type-2 fuzzy set with trapezoidal membership, which includes eight papers. The representative ratio of these articles is 72.72% (8/11). Researchers used interval type-2 fuzzy set with trapezoidal membership to solve different FMCDM problems, such as material selection (Liao, 2015), customer satisfaction in the public transportation of Istanbul (Celik et al., 2013), business intelligence for enterprise system (Zamri and Abdullah, 2013), general example (Chen and Hong, 2014b; Chen and Lee, 2010; Chen and Hong, 2014a; Lee and Chen, 2008) and the stock selection problem (Yaakob et al., 2015). Fig. 7 shows the interval type-2 fuzzy with trapezoidal membership function.

The second subcategory is the interval type-2 fuzzy set with triangular membership, which includes two papers only. The representative ratio of these papers is 18.18% (2/11). These articles used the triangular membership with the type-2 fuzzy set to solve general example (Dymova et al., 2015) and tool magazine (Shen et al., 2010). Fig. 8 shows the interval type-2 fuzzy with triangular membership.

3.3. Others

The authors placed all the articles that did not mention triangular membership or could not be placed in a specific category were placed in this category, which included nine articles only. The representative ratio of this branch is 8.23% (14/170). This category solved different FMCDM problems, such as flow control in a manufacturing system (Rudnik and Kacprzak, 2017), production line evaluation (Pei, 2013), vehicle performance evaluation (Zhang et al., 2010, 2009), general example (Gołuńska et al., 2014), supplier selection (Zhang et al., 2015), human resource management (HRM) (Mammadova and Jabrayilova, 2015), problem of ranking traded equity (Yaakob et al., 2017), convergence of heterogeneous networks (Liu and Chang, 2010), partner selection (Crispim and De Sousa, 2009), FTOPSIS use with multi-objective (Dey et al., 2014), project evaluation (Ramezani and Lu, 2012), automated guided vehicle selection problem (Sawant and Mohite, 2009) and location selection (Simić et al., 2013).

3.4. Survey paper

The final category in our taxonomy included two papers in the literature that discussed this topic and presented a survey paper. In the first article, the authors explained the TOPSIS method and provided an example of the use of this method. The representative ratio of this category is 1.17% (2/170) (Nădăban et al., 2016). The second article provides an overview of interval-valued IFS (Xu and Gou, 2017). However, the authors of most articles did not refer to this category in this topic. Fig. 9 depicts the number of papers in each category and states that type-1 fuzzy set is the most extensively used method for this topic.

We also prepared certain statistics on the topic of all articles to explain which type of membership in a type-1 fuzzy set is mostly used. Fig. 10 demonstrates the triangular membership function, which is the most widely used membership function in the type-1 fuzzy set.

The most extensively used membership function in the type-2 fuzzy set is the interval type-2 fuzzy set. Fig. 11 shows that the most widely used membership function in the type-2 fuzzy set is the trapezoidal–interval type-2 fuzzy set.

Fig. 12 illustrates that the most widely used form of fuzzy set based on the year of publication is the type-1 fuzzy set.

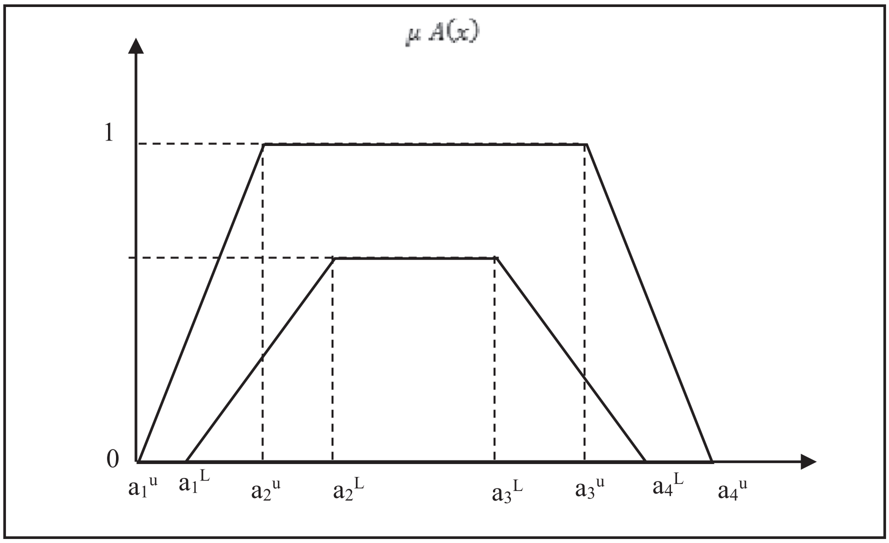


Fig. 7. Interval type-2 fuzzy set with trapezoidal membership.

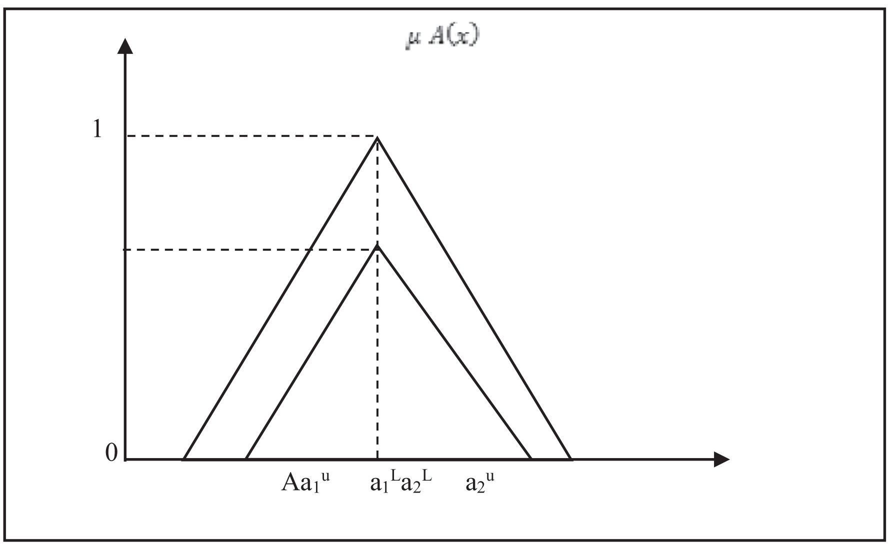


Fig. 8. Interval type-2 fuzzy set with triangular membership.

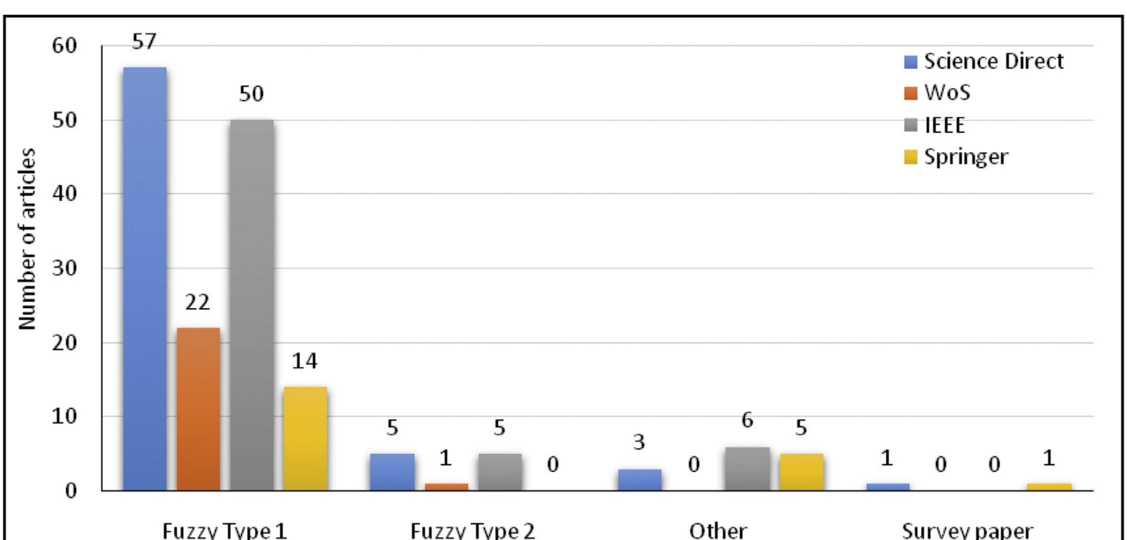


Fig. 9. Number of papers in different categories using the source's digital database.

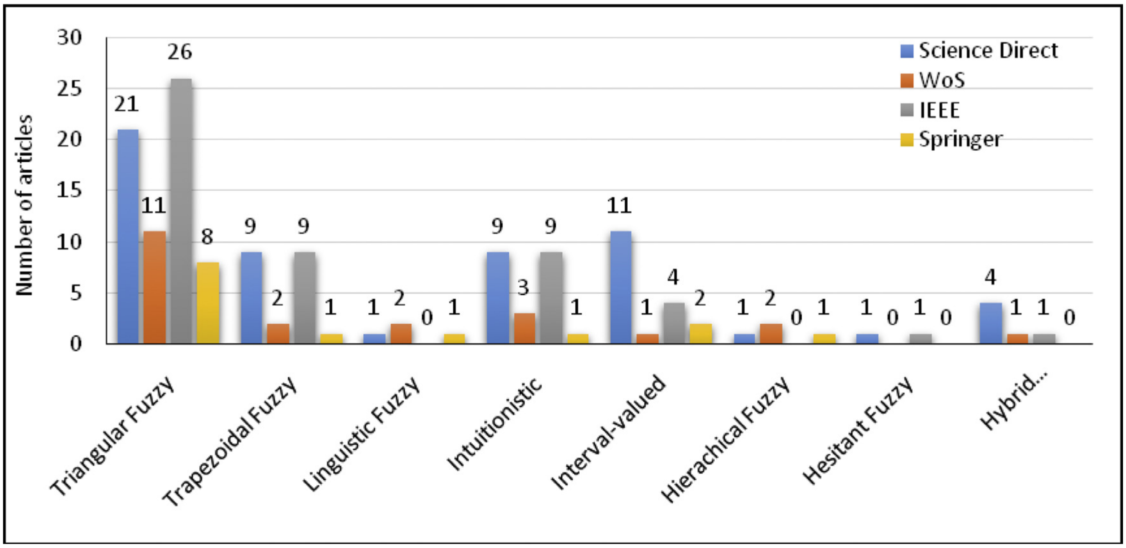


Fig. 10. Number of articles in different categories in fuzzy type-1 using the source's digital database.

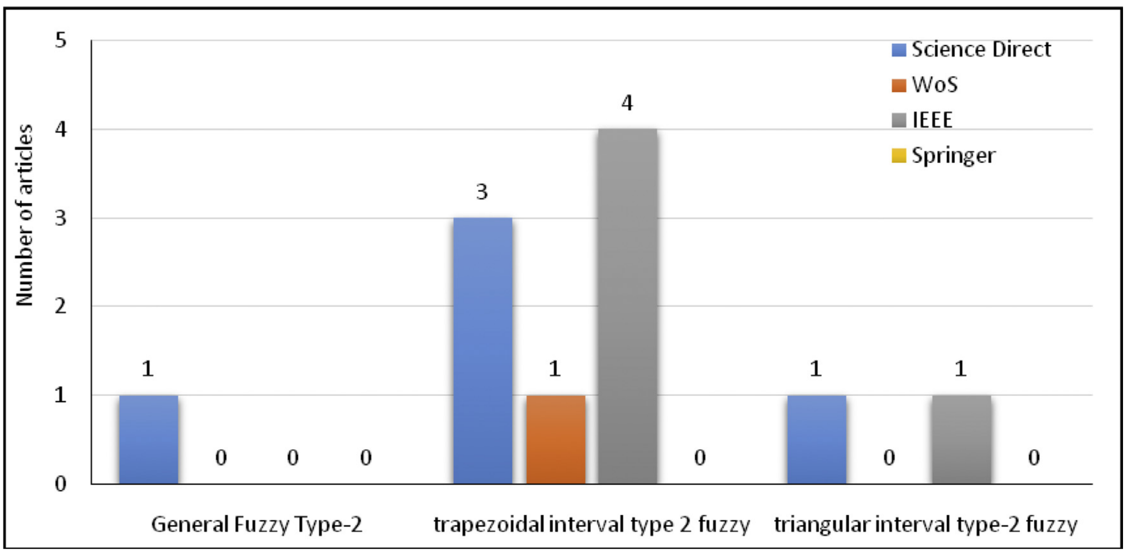
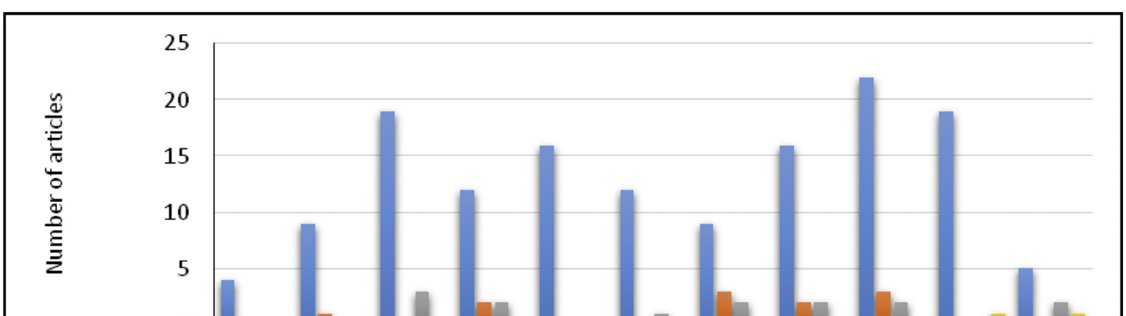


Fig. 11. Number of articles in different categories in fuzzy type-2 using the source's digital database.



	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Fuzzy Type-1	4	9	19	12	16	12	9	16	22	19	5
Fuzzy Type-2	0	1	0	2	0	0	3	2	3	0	0
Other	0	0	3	2	0	1	2	2	2	0	2
Survey	0	0	0	0	0	0	0	0	0	1	1

Fig. 12. Number of papers in different categories by year of publication.

Table 3
Distribution of papers by application area.

Area	No. of papers	%
Business and marketing management	25	14.88
SC management and logistics	26	15.47
Design, engineering and manufacturing	22	13.09
Information technology and networking applications	16	9.52
Human resource management	7	4.16
Transportation management	9	5.35
Health and safety management	4	2.38
Military applications	4	2.38
Energy management	3	1.78
Geographic information system applications	3	1.78
Water resource management	3	1.78
Other selection and evaluation applications in different topics	16	9.52
General example	30	17.85

Related papers could also be distributed depending on the application area to illustrate the areas of decision-making applications. Table 3 summarises the distribution of all papers by application.

4. Discussion

This study aims to update MCDM research and highlight the directions for research on this topic. This study differs from many previous reviews in its recentness and its concentration on the literature on fuzzy MCDM. The taxonomy of the related literature is also a contribution of this study. The taxonomy of the related literature in a research area can introduce many advantages. A taxonomy of published studies systematises various publications. In this topic, a new researcher in decision making may be overwhelmed by the large number of articles and the absence of any type of structure, thereby preventing this researcher from obtaining an overview of this research area. Several research articles discussed this topic from the preliminary viewpoint only, whereas other articles have been developed in this area. In addition, certain researchers merged decision making with other fields. Therefore, the taxonomy of the final set of literature assistance is organised from different studies and activities into an expressive, controllable and solid design. Furthermore, the frame of taxonomy presented in this study provides all researchers with important insights into the subject field in numerous ways. Firstly, this study outlines the possible directions for research on this topic. For example, in this study, the taxonomy based on the fuzzy type and fuzzy membership function shows that the researchers are interested in informing other researchers and the public about the available fuzzy type and fuzzy membership function in the MCDM. Moreover, this study emphasises a possible direction in this area. Another contribution of the taxonomy is addressing the existing gaps in the topic. The related literature that mapped the works on fuzzy membership function highlighted the most and least used spots in coverage research. For example, in this study, the taxonomy shows the fuzzy type, the most used membership function in the fuzzy environment and the attention provided to the categories of the individual type of fuzzy set and the membership in terms of use (as reflected from the popularity of their categories). The survey on the suitable and illustrative samples of the literature was combined. A taxonomy also highlights the lack of studies that use another membership function. In the related literature, the triangular fuzzy membership received considerable attention in terms of the membership function, and the most used type of fuzzy is the type-1 fuzzy set. The statistics on the subcategories of the taxonomy also emphasise the active and less active sectors in the membership function under fuzzy environment. Finally, several other taxonomies in other fields available in this research area were approved by the researchers for adoption in a certain taxonomy. A community language was improved amongst them to communicate and discuss new works in this area. Three highlights of the related literature are presented in the next sections on the basis of the surveyed works. The motivations behind the use of the MCDM with fuzzy set theory, the challenges and issues encountered by researchers in this area and recommendations for future work and solutions to difficulties are presented.

4.1. Motivations

In this subsection, we provide all the motivations derived from relevant research that stimulated researchers in this field. The motivation can be divided into several sections, namely, benefit related to the use of fuzzy set, MCDM, MCDM with management, MCDM with evaluation problems and MCDM with selection problems.

4.1.1. Benefits related to the use of fuzzy set with MCDM

In MCDM problems, the qualitative characteristics depend on the DM's judgment. Selection is frequently based on unsuitable data or personal judgment given the ambiguity of a human being's thought, which leads to inappropriate and biased decisions. The FMCDM techniques can suitably explain the DM evaluation of existing alternatives for selecting the best alternative when the criteria have subjective perceptions. Therefore, the evaluation process must work under a fuzzy environment (Singh and Benyoucef, 2011; Vahdani et al., 2011a; Cables et al., 2012; Liao, 2015; Chamodrakas et al., 2009; Wang and Lee, 2009; Yue, 2016; Gumus et al., 2016; Benitez et al., 2007; Tian et al., 2010; Zhang, 2008; Wang et al., 2007; Nădăban et al., 2016; Duan et al., 2010; Khalili-Damghani et al., 2013) to consider linguistic variables. The uncertainty and subjectivity of this method can result in weighting errors and difficulties in the process of criterion weight selection (Huang and Peng, 2012; Joshi and Kumar, 2016). For example, in the supplier selection problem, the decision making is influenced by uncertainty because ambiguity is intrinsic to the evaluation of qualitative criteria. Different DMs also determine the weight of criteria that lead to imprecise weighing. Fuzzy set theory is an important method for solving uncertainty in many real-life problems (Lima et al., 2013; Hu et al., 2015; Igoulalene et al., 2015; Osiro et al., 2014; Kar et al., 2014; Yadav and Kumar, 2009), selection problem in general (Mehlawat and Gupta, 2015; Ran et al., 2008; Perez et al., 2012) or negotiation problem (Roszkowska and Wachowicz, 2015; Xu and Chen, 2007). The DMs operate in a multi-criteria group decision-making (MCGDM) context characterised by high uncertainty and vagueness and transact with qualitative or quantitative criteria and different perspectives/stakeholders (Aloini et al., 2016; Tan et al., 2014). Thus, the idea of a linguistic variable is highly beneficial for transaction with cases that have increased complexity or are not completely determinant to be reasonably described in conventional quantitative terms, where fuzzy numbers are introduced to appropriately express linguistic variables (Cables et al., 2012; Gumus et al., 2016; Kelemenis et al., 2011; Nădăban et al., 2016; Vahdani et al., 2011b; Xie et al., 2016; Feng et al., 2016; Zamri and Abdullah, 2013; Javadian et al., 2009; Zhang et al., 2015). Zadeh firstly used fuzzy set theory with MCDM problems, which have subjective judgment, as an efficient method for solving vagueness, lack of information and ambiguity ingrained in the human decision-making process called FMCDM (Singh and Benyoucef, 2011; Krohling and Campanharo, 2011; Vahdani et al., 2013; Li et al., 2009; Wang et al., 2007). Therefore, fuzzy set theory is considered an effective method for portraying ambiguity or an uncertain environment with vagueness and other kinds of fuzziness, which is constantly involved in the field and the behaviour of manager decisions in the area (Yang and Liu, 2016; Collan and Luukka, 2014; Mishra, 2016; Zhang et al., 2010, 2015). The main contribution of fuzzy set theory is that it allows mathematical operators to be applied in the fuzzy domain through its ability to process ambiguous information (Krohling and Campanharo, 2011; Wang and Chou, 2015; Lima et al., 2013; Lee et al., 2014; Yang et al., 2011; Wang et al., 2015). Moreover, experts have occasionally encountered challenges in determining the exact weight for criteria and the membership degree for each element of the fuzzy sets treated to rank the alternatives in terms of the criteria and/or the values of criterion weights as a number in interval [0,1]. Thus, IVFS-MCDM techniques must be applied to solve fuzzy MCDM problems (Mokhtarian et al., 2014), trapezoidal membership functions (Liao and Kao, 2011) or triangular fuzzy numbers (Xu and Chen, 2007). Researchers have successfully applied fuzzy set in many research fields to solve uncertainty and ambiguity (Pei, 2013). However, knowledge on DMs is incomplete and imprecise. To handle this complex situation (uncertainty and hesitation), IFSs are used to select favourable DM preferences. IFS is a powerful tool because it manages membership, non-membership functions and hesitancy (Solanki et al., 2016; Mishra, 2016; Yue, 2016; Li et al., 2009; Wang et al., 2011; Gumus et al., 2016; Chen et al., 2016; Wan et al., 2015).

In practical problems, incomplete or unobtainable information can be encountered by researchers. For example, ambiguity in human judgment preferences cannot be exactly evaluated using real numbers. The information is frequently uncertain, and thus ambiguity and imprecision are typically present. Several evaluation criteria and alternatives are subjective considering that the description of linguistic information is qualitative in nature. Accordingly, researchers have preferred fuzzy logic (Cheng and Lin, 2012; Geng et al., 2010; Pei, 2013). An extensively used method for solving FMCDM problems is TOPSIS, where the use of real numbers to rank the alternatives may have limitations in resolving uncertainties. Thus, TOPSIS has been developed to solve the problems of MCDM with uncertain information, followed by using FTOPSIS (Krohling and Campanharo, 2011; Chamodrakas et al., 2011; Cheng and Lin, 2012; Javadian et al., 2009; Wan et al., 2016c; Yaakob et al., 2015). TOPSIS is effective in decision making but is overwhelmingly criticised for its ineffectiveness in terms of uncertainty and ambiguity involved in judgment operation. Thus, fuzzy set theory is suggested to be combined with TOPSIS. This combined process can solve imprecise information by converting it into linguistic variables (Yang et al., 2017; Krohling and Campanharo, 2011; Chamodrakas et al., 2011; Cheng and Lin, 2012; Yang et al., 2014; Perez et al., 2012; İç, 2012; Yaakob and Gegov, 2015).

In many real-world problems, DMs cannot provide numerical values to the judgments of comparison because the human preference pattern is uncertain. Fuzzy set theory has been successfully used in decision-making problems to solve extreme vagueness that emerges in the data from human judgment and preference (Zhou et al., 2012; Cables et al., 2012; Rashid et al., 2014; Xu and Zhang, 2013; Krohling and Campanharo, 2011; Park et al., 2011; Igoulalene et al., 2015; Sadr et al., 2015; Cheng and Lin, 2012; Benitez et al., 2007; Hatami-Marbini et al., 2013; Yang and Liu, 2016; Gao et al., 2008; Ran et al., 2008; Aghaie et al., 2011; White and Chandrasekar, 2017; Rudnik and Kacprzak, 2017; Rong and FAN, 2009; Chang and Tseng, 2008; Zhang et al., 2009; Mao et al., 2015).

On the one hand, type-2 fuzzy sets include more uncertainties than type-1 fuzzy sets. This type offers freedom to represent the uncertainty and fuzziness of real-world problems (Lee and Chen, 2008; Shen et al., 2010; Pei, 2015), and the type-2 fuzzy membership function can enhance the accuracy of the membership (Shen et al., 2010; Pei, 2015). Certain benefits of using soft set theory are presented (Tao et al., 2015). Many benefits of using triangular membership function are also discussed in the literature (Zammori et al., 2009; Yang et al., 2014; Madi et al., 2015; Roszkowska and Wachowicz, 2015). The hesitant fuzzy linguistic term set is a useful tool for describing subjective cognitions in people in the decision-making process. MCDM involves two important steps: (1) determining the criteria weights and (2) obtaining a suitable ranking of alternatives (Gou et al., 2017; Wang et al., 2014).

4.1.2. Benefits related to the use of MCDM

Research interest in MCDM is increasing (Yaakob and Gegov, 2015) because MCDM is regarded as a prime part of operation research, decision science and expert system, which contains multiple alternatives and criteria. The main goal of MCDM is to determine the optimal alternative(s) from a set of obtainable alternatives versus the selected criteria. MCDM approaches can provide resolutions for numerous domains of science, such as management, society, economics, engineering and different problems (Vahdani et al., 2011a; Park et al., 2011; Vahdani et al., 2013; Singh and Benyoucef, 2011; Javadian et al., 2009; Aghaie et al., 2011; Abd et al., 2014; Büyüközkan and Güleryüz, 2015; Zhang et al., 2015; Wang and Qin, 2008; Wang et al., 2007; Madi et al., 2015; İç, 2012; Hatami-Marbini and Kangi, 2017; Rudnik and Kacprzak, 2017; Liao and Kao, 2011; Walczak and Rutkowska, 2017; Cui and Yang, 2009; Yaakob et al., 2017; Hatami-Marbini et al., 2013; Wan et al., 2016a), such as higher vocational education (Li et al., 2016), IT projects (Xing et al., 2009), mobile heterogeneous networks (Liu and Chang, 2010; Feng et al., 2016), optimisation problems (Yaakob et al., 2015; Hatami-Marbini and Kangi, 2017), NPD (Özdemir et al., 2010) and software development (Mehlawat and Gupta, 2015). Most MCDM methods use subjective or objective weight given the difference of alternative evaluations based on their importance (Dammak et al., 2015). Several researchers also combined multiple attribute decision making (MADM) with MCDM. Many studies were completed on the weight of evaluating a totally unknown or intelligible index. In real life, a condition with complete or incomplete information occurs infrequently. In most cases, the MADM problem must be solved using fuzzy set theory (Fu, 2008; Wang et al., 2011; Wang and Xu, 2010; Xing et al., 2009; Yuxun, 2010; Wang and Qin, 2008).

MADM, multi-attribute group decision making (MAGDM) (Li et al., 2010, 2009; Ervural et al., 2015) and dynamic MAGDM (DMAGDM) (Su et al., 2011) are concerned with selecting the optimum alternative on the basis of a group of DMs to evaluate the attribute (criteria). They are applied in different fields, such as medicine, society, economy and management (Li and Zhang, 2009; Baykasoğlu and Gölcük, 2015; Xu and Zhang, 2013; Wei and Shengbao, 2008; Chamodrakas et al., 2011; La Scalia et al., 2011).

TOPSIS is a common and widely used technique for solving MCDM (Pei and Zheng, 2010; Zhang et al., 2015;

Yuxun, 2010; Madi et al., 2015; Xing et al., 2009) and MADM (Chamodrakas et al., 2011), but it is not a favourable judgment method for solving all MCDM problems. In practical problems, researchers have typically attempted to select numerous existing techniques such that it seems to be maximally suitable for the preferences of DMs and the specificity of the case. In general, technique selection to solve a problem in the MCDM is a context-dependent problem (Dymova et al., 2015; Chen, 2011; Jiang et al., 2011).

MCDM solves different problems in the aforementioned fields. In the medical field, MCDM can help doctors in classifying the different diseases of their patients, and the system can provide a support decision for determining the patient who should be served first. In the management field, a leader cannot make a decision when a problem has various alternatives or criteria. MCDM helps managers select the optimum alternative from the set of alternatives. Moreover, group decision making (GDM) is crucial because the knowledge of the group DMs is better than that of one expert in one problem. In addition, in engineering and other fields, MCDM can provide a support decision to managers. Finally, MCDM can work with different fields to solve many real-life problems.

4.1.3. Benefits related to the use of MCDM in the management field

An important field in which MCDM is involved in is management in all its forms, such as trading, financial markets, companies, suppliers and commercial markets. Companies must develop new products to maintain their commercial value amidst increasing competition in global markets. NPD is a major function of companies. Companies have short product lifetime cycles. Thus, improving new product platforms and products that achieve sensible requests on quality, price, safety and performance is important. NPD interprets this idea as a sensible material asset that is constructed around well-defined stages. Several decision points are found in each stage, where the management decides on the future of a project. A critical decision when managing NPD projects is to select the idea of a new product. Many studies have deduced that managers must finish the NPD projects that they have started (Kahraman et al., 2007; Özdemir et al., 2010), such as green product development (Wang et al., 2015) and project management (Zammori et al., 2009). Moreover, cities that are densely populated and are undergoing economic growth must use scientific methods to improve the management of an economy in large cities. One of these methods is MCDM (Rao et al., 2015; Tan et al., 2014). ICT companies must consider effective planning to provide various services. These companies typically rely on staff experience. Therefore, decision-making techniques can be greatly utilised (Li and Chou, 2014) and have become necessary in heterogeneous networks (Liu and Chang, 2010), electronic marketplace management (Chamodrakas et al., 2009) and HRM (Mammadova and Jabrayilova, 2015; Polychroniou and Giannikos, 2009). Considerable research has discussed managing the reuse of freshwater, preventing floods that threaten human life and destroys infrastructure and using MCDM to manage such issues (Sadr et al., 2015; Lee et al., 2014). Furthermore, the concept of OI has generated extensive interest in the previous decade. OI uses external resources and partners to develop the innovation ability of an organisation; it depends on the concept that invention and innovation can emerge inside and outside company walls (Aloini et al., 2016; Cheng and Lin, 2012). SC management (SCM) has drawn considerable attention from researchers given its pervasive nature. SCM is the process of managing the smooth flow of goods and services from origin to destination. The various factors that play important roles in this process are cost price, risk factor, optimised inventory levels, improved customer service and maximised customer satisfaction. The most effective supplier shall be the one who can provide maximum satisfaction, is reliable, provides the best-quality product, minimises time delay (Solanki et al., 2016; Igoulalene et al., 2015; Lima et al., 2013; Gao et al., 2008; Xiao and Wei, 2008; Feng, 2012; Zhang, 2008) and utilises outsourcing management (Wan et al., 2015).

On the other hand, MCDM techniques are strategies for evaluating services and providing support decision to the management of the transportation to manage road safety, public transport, ports and overseas oil–gas transport through a scientific method to obtain the optimal possible solution (Celik et al., 2013, 2009; Huang et al., 2015; Bao et al., 2012). R&D management (Li, 2013; Collan and Luukka, 2014) and MCDM are also used by companies in managing and developing structures that lead to their success (Kelemenis and Askounis, 2009) and determining the application of GM (Mittal and Sangwan, 2014). MCDM can be used in electric power management, risk reduction and safety maintenance (Guowei et al., 2009).

The management of most projects is difficult and involves risk because they contain many actions related in a complex way. Therefore, many network techniques must be developed to identify the CP, which locates project fulfilment time. In fact, once the CP is identified, project managers can concentrate on it to control time and costs and efficiently allocate resources under the supposition that activities with short allowable delay are the most dangerous ones (Zammori et al., 2009; Haleh et al., 2010).

4.1.3.1. Benefits related to the use of MCDM in evaluation problems. MCDM is a powerful method that is commonly utilised to solve the evaluation problems that involve various and typically inconsistent criteria (Mao et al., 2015). Thus, evaluating product development and product line becomes increasingly difficult, and uncertain information increases. Thus, evaluating MCDM is necessary (Pei, 2013; Geng et al., 2010). Moreover, the development of technology, science and economy leads to increased uncertainties involved in project management. Thus, evaluating project risk is a crucial task (Guo and Zhang, 2009).

The evaluation process must be conducted to enhance quality (Li and Zhao, 2014; Espinilla et al., 2012). The objective is to support DMs in the evaluation process by presenting different options (Cables et al., 2012). In several branches, such as scientific journals and research evaluations (Li and Zhao, 2014), quality of service (Benitez et al., 2007) and patient safety (Wang and Chou, 2015), MCDM is effective, and the evaluation result can be used by managers as a benchmarking tool (Benitez et al., 2007; Gou et al., 2017) and for evaluating suppliers on the basis of their performance (Osiro et al., 2014).

4.1.3.2. Benefits related to the use of MCDM in selection problems. The important aim of MCDM is to select an improved substitute from a set of alternatives on the basis of a set of criteria and help managers make decisions; thus, it is widely used in the selection problem (Xu and Chen, 2007; Chen and Niou, 2011; Krohling and Campanharo, 2011; Fan and Feng, 2009; Vahdani et al., 2011b). MCDM is also one of the most researched topics in recent years (Tian et al., 2010). It is used to solve the selection problem in many topics and is combined with fuzzy methods, such as supplier selection (Hu et al., 2015; Kar et al., 2014; Xie et al., 2016; Liao and Kao, 2011; Bai et al., 2014; Bandyopadhyay, 2016; Wood, 2016; Niyigena et al., 2012; Guo et al., 2010), new product design selection (Özdemir et al., 2010; Aikhuele and Turan, 2016) or evaluating remanufacturing product design (Wang and Chan, 2013), optimal location selection (Senvar et al., 2016; Mokhtarian et al., 2014; Zhou et al., 2012; Chou and Chang, 2009; Simić et al., 2013), qualified human resources selection (Kelemenis and Askounis, 2010; Perez et al., 2012), engineering design material selection (Vinodh and Girubha, 2013; Liao, 2015), suitable robot selection (Rashid et al., 2014), most energy-efficient network selection

(Chamodrakas and Martakos, 2012b), vessel selection (Yang et al., 2011), ranking renewable energy alternatives (Gumus et al., 2016), weapon system selection (Yang et al., 2014), software selection (Lingyu et al., 2009), production strategy selection (Chang and Tseng, 2008) and technology selection (Wan et al., 2016b). Portfolio theory is considerably used in the economic and financial sectors (Yang and Liu, 2016; Khalili-Damghani and Sadi-Nezhad, 2013a).

4.2. Open challenges and issues

This section explains all the open challenges and researchers' issues that were collected from the related literature. These challenges include those related to MCDM methods and DMs; challenges from SCM, the selection problem, evaluation and the energy problem; and other challenges encountered by researchers in this field.

4.2.1. Challenges related to MCDM methods

In real-world problems, the most important challenges that researchers encounter in MCDM methods include (1) unquantifiable information, (2) incomplete information, (3) unobtainable information, (4) uncertain information, (5) partial ignorance, (6) ambiguous information and (7) vague information. DMs use linguistic terms and cannot determine the weight in real numbers. Therefore, the problems that include this information cannot be solved easily. Numerous researchers have mentioned this challenge (Wang et al., 2007; Mishra, 2016; Xu and Zhang, 2013; Huang and Peng, 2012; Chen, 2011; Lee et al., 2014; Chamodrakas et al., 2011; Vahdani et al., 2013; Hatami-Marbini et al., 2013; Vahdani et al., 2011b; Xu and Chen, 2007; Bai et al., 2014; Wang and Qin, 2008; Hatami-Marbini and Kangi, 2017; Mao et al., 2015; Li and Zhang, 2009; Dymova et al., 2015; Zamri and Abdullah, 2013; Chamodrakas et al., 2009; Pei, 2015; Wan et al., 2015; Kahraman et al., 2007; Wan et al., 2016b; Shen et al., 2010; Liu and Chang, 2010; Niyigena et al., 2012; Yaakob and Gegov, 2015; Mammadova and Jabrayilova, 2015; Wang et al., 2015; Khalili-Damghani et al., 2013; Huang et al., 2010; Büyüközkan and Güleryüz, 2015; Wood, 2016; Kelemenis et al., 2011). Moreover, many scholars have discussed the challenges in losing data when converting expert opinions from linguistic terms to fuzzy numbers or in the aggregation processes or when unifying heterogeneous information. This situation leads to inaccurate results (Dymova et al., 2015; Gou et al., 2017; Hatami-Marbini and Kangi, 2017; Niyigena et al., 2012; Chu and Liu, 2014; Wan et al., 2016c; Yang et al., 2011; Khalili-Damghani and Sadi-Nezhad, 2013a). The vagueness of expert opinions indicates that real numbers cannot be used to represent such opinions. Thus, distance measurement must be used in selecting PIS and NIS. Many scholars also mentioned a challenge with distance measurement in FTOPSIS (Wang et al., 2014; Aghaie et al., 2011; Niyigena et al., 2012; Ran et al., 2008; Mehlawat and Gupta, 2015; Yuxun, 2010). Another new challenge in credibility theory is the fuzzy variables based on the credibility measure (Pei, 2015) and the similarity measurement between fuzzy sets (Haleh et al., 2010; Niyigena et al., 2012). The aggregation process in the TOPSIS method and other extended methods has problems that affect the ranking results (Chamodrakas et al., 2009; Chamodrakas et al., 2011; Gou et al., 2017; Wan et al., 2016a, 2016c). The independent criterion is also a challenge in MCDM and requires further research (Baykasoğlu and Gölcük, 2015; Yang et al., 2011; Joshi and Kumar, 2016). The type-2 fuzzy set used with the TOPSIS method has several drawbacks and limitations (Dymova et al., 2015; Chen and Hong, 2014b). Furthermore, when the IVFS is used to represent a subjective judgment, covering the entire range may be a major challenge. The results will be inaccurate (Rong and FAN, 2009), thereby complicating the determination of the precise membership degree for each element of the fuzzy sets by using a number in the interval [0–1, (Mokhtarian et al., 2014)], and the membership status in IFS is determined (Rong and FAN, 2009; Wan et al., 2016c). The IVIFN disregards interval hesitation degree (Wan et al., 2016c), and the implication of inclusion between IVIFNs is unclear (Yue, 2016). Fuzzy set theory has a limitation in the decision-making process because a single membership degree provides inadequate information about uncertainty (Geng et al., 2010). Finding the optimum decision when working with a decision-making group is difficult because of the differences in the knowledge between the decision makers. Furthermore, aggregating the opinion of experts affects the weight of the criteria that lead to an effect on the final decision (Geng et al., 2010; Zhang et al., 2010; Wan et al., 2016b). Moreover, the large amount of math involved may inhibit workers in this field who do not have in-depth knowledge of mathematics (Yang et al., 2011). The principle that the optimal alternative is the closest to the ideal solution and simultaneously the farthest to the negative solution may also be contradictory (Chamodrakas et al., 2009). A weakness of the classic FTOPSIS is the difficulty in recognising the optimum selection when two or more alternatives have the same distances from the PIS and NIS (Li and Chou, 2014). FTOPSIS is not concerned with the relative importance of distances between PIS and NIS with regard to the reference points (Li et al., 2010). In addition, FTOPSIS cannot solve fuzzy MCGDM because the divergent views of experts cannot determine the degree of membership (Li et al., 2010; Wan et al., 2016b; Zhang et al., 2009; Joshi and Kumar, 2016), and the existing aggregation methods cannot solve the heterogeneous MCGDM problems (Wan et al., 2016c). Another challenge is translucence, in which existing TOPSIS methods have low translucence and are therefore unable to track the performance of benefit and cost criteria (Yaakob et al., 2016, 2017). Several researchers mentioned zero problems in which the alternatives in certain situations cannot be ranked (Chen et al., 2016; Yang et al., 2011). The main drawback of traditional TOPSIS is ranking abnormality (Feng et al., 2016). The difficult discrimination between multiple variants of TOPSIS is another challenge (Madi et al., 2015). Furthermore, existing FTOPSIS methods are mostly afflicted by the lack of preservation of the fuzziness up to the end of the calculation process (Hatami-Marbini and Kangi, 2017). Moreover, DMAGDM problems and the process of solving them pose difficulties to MCDM methods (Su et al., 2011). Handling FMCDM problems is based on interval type-2 fuzzy sets (Chen and Lee, 2010) or fuzzy preference relations (Chen and Niou, 2011). The removal of the dismissed attributes, especially in large and complicated problems, is also a considerable challenge because not all the attributes are necessary to find the final decision (Pei, 2013), represent the ideal and anti-ideal solutions used as minimum and maximum values and evaluate the criteria of the values that may not cover all possible packages to be evaluated (Roszkowska and Wachowicz, 2015). Another challenge is finding an optimisation model on the basis of the maximising deviation method, which can utilise and determine the weight of attributes and calculate the relative closeness of each alternative to the hesitant PIS (Xu and Zhang, 2013). A relative closeness for each alternative offers only one possible solution to an FMCDM problem but cannot reflect the whole picture of all possible solutions for this problem (Yang et al., 2011). A serious problem may also arise from the analysis process of subjective judgments concerning appraisal behaviours and errors of positive or negative leniency (Chen, 2011). Fuzzy extent analysis has several issues, such that the technique cannot completely utilise all fuzzy comparisons of the matrix information and the allocation of an illogical zero weight to certain useful decision criteria. This process may achieve improper decisions (Wang et al., 2015). Diverse opinions from stakeholders in decision making (Sadr et al., 2015) and solving MCDM problems under the interval-valued intuitionistic fuzzy environment are also a problem for MCDM methods (Wang et al., 2011). In addition, challenges encountered by several researchers are the focus of this study, but this challenge is not the optimum approach to ranking fuzzy numbers (Wan et al., 2016a). Another challenge is transforming MCDM problems with triangular fuzzy interval-valued weight and indexes into MCDM problems (Fu, 2008). The analysis of the performance of the resulting system is frequently difficult given limited knowledge (Mehlawat and Gupta, 2015). Most MCDM techniques do not manage the end-user attitude, which may be a major factor in decision making but depends only on the subjective weights of DMs (Wang and Lee, 2009). Most fuzzy linguistics are defined only on one side, which is a positive fuzzy number (Zamri and Abdullah, 2013). The present study discusses the challenges of transforming complex reasoning into a simple mathematical calculation (Guo-wei et al., 2009).

4.2.2. Challenges related to decision makers

In the related literature, many challenges were encountered by DMs, which are presented in this section.

In this study, the approaches do not consider the degree of effect of DMs. This problem is crucial because the results can change (Yaakob and Gegov, 2015). In many real-world problems in decision making, DMs provide their preferences for each alternative. The preference information provided by DMs is generally vague because the socioeconomic environment is complex, and uncertainty and ambiguity in DM preferences may exist considering the time pressure in making the decision, the lack of knowledge or data or the incomplete attention and information processing capacities of DMs (Wei and Shengbao, 2008; Park et al., 2011; Khalili-Damghani and Sadi-Nezhad, 2013a; Khalili-Damghani et al., 2013; Mishra, 2016; Li et al., 2016; Tao et al., 2015; Wan et al., 2015; Wang and Xu, 2010; Tian et al., 2010; Madi et al., 2015). Moreover, DMs cannot express their evaluations through a single linguistic term because of ignorance and incomplete information (Jiang et al., 2011). An important problem related to DMs but is disregarded in the decision-making process is the reliability of the information and the experience of DMs (Yaakob and Gegov, 2015). Another challenge is that DMs focus on the technical index but disregard the project cost, thereby leading to high project costs (Xie et al., 2016). The external pressures of shareholders on the DMs may also affect the latter's opinions (Celik et al., 2009). Redundant criteria may also cause considerable unnecessary burden on DMs (Pei, 2013).

GDM is a decision-making problem category in which multiple DMs work together to analyse problems, evaluate alternatives and select the optimum solution from the available alternatives. In most real-world problems, DMs may not be eligible to offer preferences for alternatives to a certain degree given the absence of the exact or sufficient level of knowledge related to the problem or the difficulty of evaluating the alternatives. Moreover, different perspectives of DMs contribute to the problem of aggregating various opinions (Yue, 2016; Aloini et al., 2016; Yue and Jia, 2015; Khalili-Damghani and Sadi-Nezhad, 2013b; Geng et al., 2010). Heterogeneous MCGDM problems are also complex and interesting in real-world applications of decision making (Li et al., 2010). The solution to the problem of consensus reaching and its related GDM has been discussed (Gołuńska et al., 2014). Obtaining appropriate weights is also difficult, and weights are typically different for each standard despite teamwork, given the different experiences and scientific visions of the evaluators and other factors that lead to varying weights (Li and Zhao, 2014). The evaluation of alternatives on each criterion is problematic for DMs given the diversity and incommensurability of the outsourcing criteria (Wan et al., 2015).

4.2.3. Challenges of the SCM

A difficult task in management is decision making, that is, selecting the optimum alternative among a set of alternatives which may include certain contradictory and incommensurable criteria. The continuing development of society and economy has led to changes in decision environments (Yue and Jia, 2015). The most important issue in MCDM is SCM. In related literature, numerous studies have been conducted to solve this problem. Many factors represent a challenge in managing SC risks (Zhang, 2008). The current complexity of SC activities necessitates organisation and coordination between SC companions to exploit efficiency, which is considered by experts as a major SC coordination problem (Igoulalene et al., 2015). The selection problem is the most important issue in the SC problem, which is explained in detail in the next section.

4.2.3.1. Challenges of the selection problem. The supplier selection problem, such as the selection criteria, is an issue that requires further research. In the literature, numerous criteria are used and unused by every organisation (Bandyopadhyay, 2016). Moreover, many factors affect the process, and the qualitative and quantitative weights make the selection of the optimum alternative a complex and challenging task (Vahdani et al., 2013; Singh and Benyoucef, 2011). The selection problem based on uncertain information is a complex task (Wang et al., 2007).

In the related literature, many studies have been conducted to solve the selection problem in different ways. The selection process is generally applied to several problems containing numerous uncertainties (Ervural et al., 2015), such as NPD (Kahraman et al., 2007), human resources (Kelemenis et al., 2011; Polychroniou and Giannikos, 2009), supplier selection (Lima et al., 2013; Hu et al., 2015; Liao and Kao, 2011; Osiro et al., 2014; Solanki et al., 2016; Xiao and Wei, 2008; Kar et al., 2014; Feng, 2012; Guo et al., 2010), robot selection (Rashid et al., 2014), optimum combat response selection (Krohling and Campanharo, 2011), IT selection (Kelemenis and Askounis, 2010; Wang and Lee, 2009; Chang and Tseng, 2008; Gao et al., 2008), water management (Sadr et al., 2015; Minatour et al., 2015), project selection (Yeh et al., 2009; Khalili-Damghani and Sadi-Nezhad, 2013b), service of quality (Benitez et al., 2007; Feng et al., 2016; Chamodrakas and Martakos, 2012a), fuel bus selection (Vahdani et al., 2011b), material selection (Yang et al., 2017; Vinodh and Girubha, 2013), portfolio selection (Yang and Liu, 2016), weapon system selection (Yang et al., 2014), personal selection problem (Perez et al., 2012) and team member selection (Kelemenis and Askounis, 2009). A challenging and famous type of MCDM problems that include quantitative and qualitative criteria is facility location selection (Mokhtarian et al., 2014; Zhou et al., 2012; Chou and Chang, 2009; Senvar et al., 2016) and automated guided vehicle selection problem (Sawant and Mohite, 2009).

4.2.4. Challenges with the evaluation problem

In MCDM, an important issue is the evaluation process, which is a complex problem (Ervural et al., 2015; Run-qi, 2008). Current evaluation methods based on ambiguous sets do not satisfy our objective of ensuring effectiveness and accuracy (Geng et al., 2010). Moreover, the researchers used MCDM to evaluate different problems, with the main challenge being the evaluation of sets with uncertain information (Cheng and Lin, 2012). Studies have used evaluation to solve problems, such as patient safety evaluation (Wang and Chou, 2015), customer evaluation (Chamodrakas et al., 2009), supplier evaluation (Osiro et al., 2014), project risk evaluation (Guo and Zhang, 2009; Ramezani and Lu, 2012), mobile phone evaluation (Büyüközkan and Güleryüz, 2015) and bidding process preparation (Cui and Yang, 2009). The evaluation process also has certain issues when working with GDM. The first issue is to determine a set of appropriate weight multi-criteria that evaluates a group of DMs with a frequently difficult job. The determination of random weights for criteria by using subjective term judgments will increase subjectivity and decrease decision accuracy. The second issue is reaching an effective collective consensus from different provisions of two evaluators (Li and Zhao, 2014). The problem is managing multi-criteria to evaluate the reuse of a building for residential living, retail, training centres or other purposes (Tan et al., 2014). Finally, an evaluated alternative can receive high scores when the reported capabilities are greater than the objective criteria (White and Chandrasekar, 2017).

4.2.5. Challenges with the energy problem

Studies that discussed the energy problem and the solutions to these problems through MCDM methods are found in the related literature. The energy problem has several issues, such as energy security, environmental sustainability and economic competitiveness (Gumus et al., 2016; Chamodrakas and Martakos, 2012b; Guo-wei et al., 2009; Krohling and Campanharo, 2011; Li and Chou, 2014). Processing uncertain data and human judgment in this problem is difficult (Krohling and Campanharo, 2011; Gumus et al., 2016). In addition, many studies are subjected to significant uncertainties given sector aggregation, linearity assumptions and uncertainties, which are not sufficiently integrated with a fuzzy MCDM model alone (Gumus et al., 2016).

4.2.6. Other challenges

In this section, we present several challenges that the researchers have attempted to solve but still required additional solutions, such as fuzzy group problems, which represent the hierarchical structure for DM preferences on the fuzzy priority of goals and their associated fuzzy aspiration levels (Khalili-Damghani et al., 2013). The danger of floods and the destruction they cause to human lives and economic losses (Lee et al., 2014) and the rapid growth in the traffic sector and public transport, especially road transport and road safety problems, are also discussed (Bao et al., 2012; Celik et al., 2013). A problem with evaluation was discovered in this study (La Scalia et al., 2011). The determination of the distribution of the completion time of a project is difficult and frequently inapplicable (Zammori et al., 2009). Similar plans lead to a decrease in the benefits of marketing strategies (Benitez et al., 2007). In R&D projects, the challenge is profitability-based assessment of financial projects, which refers to the difficulty of estimating the size and timing of future project cash flows; project ranking is also a real problem for companies (Collan and Luukka, 2014). Furthermore, the risks of IT projects must be considered and quantified. However, risks cannot be exactly expressed by real numbers (Xing et al., 2009). A promising challenge in the OI paradigm is, in fact, building cross-enterprise processes to leverage internal strengths with partner competencies and knowledge to provide new/superior products/services, reduce risk and possibly open new market segments (Aloini et al., 2016; Crispim and De Sousa, 2009). The corporate survival pattern is a major reason for the decline in technological innovation (Cheng and Lin, 2012). Many barriers to implementing GM have been identified (Mittal and Sangwan, 2014).

4.3. Recommendations

To support and extend research in the future, additional study issues must be explored. This section presents all the recommendations extracted from the related literature.

4.3.1. Recommendations to researchers

The recommendations to researchers were classified into two branches, namely, the recommendation to researchers in general and to governments and managers. The former can be classified further into recommendation as limitations in many articles in the related literature and other recommendations to researchers.

The recommendations to researchers are presented in MCDM under a fuzzy environment. Many researchers have claimed that the proposed method in their studies was flexible and could be easily applied to other MCDM problems. This claim is a recommendation for researchers to use the proposed method in these studies in future works. The modified FTOPSIS method has been presented in their studies and applied to the case study, but it could be used for other fields to make the optimum decision; these fields include engineering and management, business problems and human resources. Examples of such applications include project selection, production line evaluation, NPD, supplier selection and location selection problems when available data are inexact, vague, imprecise and uncertain in nature (Vahdani et al., 2011a; Baykasoğlu and Gölcük, 2015; Mishra, 2016; Polychroniou and Giannikos, 2009; Nădăban et al., 2016; Mokhtarian et al., 2014; Chen, 2011; Krohling and Campanharo, 2011; Liao and Kao, 2011; Park et al., 2011; Chamodrakas et al., 2011, 2009; Gumus et al., 2016; Yue and Jia, 2015; Xing et al., 2009; Chang and Tseng, 2008; Büyüközkan and Güleryüz, 2015; Wang et al., 2014; Mammadova and Jabrayilova, 2015; Lingyu et al., 2009; Xu and Zhang, 2013; Li and Chou, 2014; Vahdani et al., 2013; Khalili-Damghani and Sadi-Nezhad, 2013b; Su et al., 2011; Li et al., 2010; Bai et al., 2014; Khalili-Damghani and Sadi-Nezhad, 2013a; Wan et al., 2016b; Fu, 2008; Xiao and Wei, 2008; Kar et al., 2014; Özdemir et al., 2010; Pei, 2013; Wang and Qin, 2008). The researchers suggested using MCDM in the future when facing one of the aforementioned problems.

In this study, the proposed approach is recommended to measure the quantitative parameters (La Scalia et al., 2011). Moreover, several researchers recommended using another type of fuzzy set in their approaches or applied the same type of fuzzy set to solve other problems (Tao et al., 2015; Hu et al., 2015; Yang et al., 2011; Igoulalene et al., 2015; Wan et al., 2015; Senvar et al., 2016; Li et al., 2009; Osiro et al., 2014; Fu, 2008; Kar et al., 2014; Rudnik and Kacprzak, 2017; Yue and Jia, 2015; Wan et al., 2016c). In the current study, two changes in the algorithm of Hwang are introduced. Firstly, normalisation was removed because it was unnecessary, and all the values were measured within the same rank. Secondly, the imaginary alternatives that conform to the vocabulary terms were introduced (Cables et al., 2012).

Several studies also recommended comparing Hwang's approach with other MCDM methods or applying other methods, such as AHP, ELECTRE III, PROMETHEE II, VIKOR, ANP (Kelemenis et al., 2011; Senvar et al., 2016; Liao, 2015; Kelemenis and Askounis, 2010; Yang et al., 2014; Perez et al., 2012; Hatami-Marbini and Kangi, 2017; Dammak et al., 2015; Chamodrakas and Martakos, 2012a; Aloini et al., 2016) and fuzzy hierarchical TOPSIS (Kahraman et al., 2007; Bao et al., 2012), or aggregating it with other methods (Collan et al., 2015). Another study recommended comparing the impact of distance measures on MCDM methods (Dammak et al., 2015). In the present study, the recommendation is to perform benchmarking with other ports (Celik et al., 2009).

In the future, the application of the Takagi–Sugeno technique can be explored (Lima et al., 2013). Another future research can focus on the values of hybrid criteria under a fuzzy environment in the location selection problem (Rao et al., 2015) and on building an electronic negotiation system (Roszkowska and Wachowicz, 2015) that can focus on discovering the possibility of using alternative fuzzy set design methods (Madi et al., 2015). This study can help in modelling uncertainty in real-world problems. The method must be developed properly under a fuzzy environment (Khalili-Damghani and Sadi-Nezhad, 2013b). Another recommendation is to combine qualitative and quantitative methods to solve additional decision problems in a fuzzy environment in a scientific and rational manner (Hu et al., 2015). In addition, this study recommends using demographic characteristics not applied to the assessment process for different countries, transport systems and/or number of respondents (Celik et al., 2013). Another recommendation is to study hotel evaluations (Benitez et al., 2007). Another study recommends improving new generalised geometric aggregation operators of TIFNs in the decision analysis field (Wan et al., 2016a). In the future, various information contents can be integrated to find a rich and accurate user profile (Mao et al., 2015). Other suitable MCDM methods can also be used to improve this method by utilising other attributes because, in this method, different criteria are involved in determining the most similar fuzzy number to the required fuzzy number. This finding indicates that this approach can use other criteria (Haleh et al., 2010). In the future, studies on distance measurement can modify this method to other hybrid approaches (Hatami-Marbini et al., 2013). This study has opened paths for additional applications of credibility theory and hybrid methods in the COTS product selection problems (Mehlawat and Gupta, 2015). Further improvements to this method can be used to create various mathematical programming models, such as fuzzy goal programming and dynamic programming (Ervural et al., 2015). This study also recommended working on several evaluation methods with simple ideas, unpretentious operations and well-founded treatment (Yue, 2016). In the future, this approach will be implemented and analysed in developing and developed financial markets after the financial crisis (Yaakob et al., 2017). Another study recommended applying other types of fuzzy sets in this approach (Li and Zhang, 2009). As a future direction, for different countries, transportation systems and/or number of respondents, the demographic characteristics, which are not used in the evaluation process, can be considered (Celik et al., 2013). Additional research can be productive if these considerations are regarded, and the results can be returned to the same hotel in different seasons to determine customer satisfaction with the quality of service (Benitez et al., 2007). Another research recommended using intuitionistic fuzzy variables in the optimisation field and of intuitionistic fuzzy variables containing more ambiguous information than that of normal fuzzy variables (Pei, 2015), a method that is more practical and flexible (Wan et al., 2016b). One research recommended an in-depth study of the decision matrix merits of FTOPSIS given the various weighting methods for different criteria (Collan and Luukka, 2014). Several researchers recommended improving their methods, such as the evaluation criteria and their fuzzy weight (Zhou et al., 2012).

The reason for considering DM preferences in assessing higher vocational education development levels was verified (Li et al., 2016). Other recommendations were to produce integrated weights by combining the objective and subjective weights (Wang et al., 2007; Singh and Benyoucef, 2011) and including the membership degree for each class and extending the classification (Walczak and Rutkowska, 2017). Another recommendation was to develop the optimisation of the membership function parameters to make it better than the traditional one (Zhang et al., 2009, 2010). This study also recommended further research to enhance the work efficiency of the buyers, save on social costs and achieve a mechanism for developing an open software flat plan for buyers. Consequently, buyers will be the most important research object in the future. The inclusion of compelling and quantification indicators into the decision is another research object (Cui and Yang, 2009). Another study recommended a precise study on the differences in primary sets of the model and on clarifying other effects (Wang and Chou, 2015). The proposed method requires further study to verify its effectiveness in the future (Li and Chou, 2014). Another direction for future work is that the weight information of DMs may also be a linear inequality-type information, which is a difficult but promising research problem (Xu and Chen, 2007). Another recommendation is to improve the proposed methodology into a comprehensive material design system and increase the knowledge acquisition for automation (Yang et al., 2017). This study recommended solving the problem on fuzzy ratings and that fuzzy weights must result in fuzzy relative closeness coefficients, not crisp numbers, which are implemented in this study (Gao et al., 2008). The study recommended enhancing the proposed method for use in synchronised design applications. Moreover, the proposed method can be integrated with other modules, if available, and will be most useful to modern design engineers (Liao, 2015). This study suggests that several equations require additional details to aggregate the relative importance of every DM to the aggregation process (Kelemenis and Askounis, 2009). The authors of this research also mentioned that the robustness and reliability of the proposed system must be checked, and the results must be compared with those of the traditional process (La Scalia et al., 2011). The use of a belief distance measurement as an alternative optimisation in MCDM was recommended (Jiang et al., 2011). Another recommendation is for the proposed method to undergo further testing to enhance its practical importance, update data and improve continuously (İç, 2012). Chen and Lee's technique has two drawbacks. Firstly, it provides an incorrectly preferred order of the alternatives in several states. Secondly, the preferred order of the alternatives changes if other alternatives are added (Chen and Hong, 2014a). The results provide the PCB industry with new directions for future work to improve the general performance of this method (Cheng and Lin, 2012). The next objective is to implement and analyse the performance of the approach in developing and developed financial markets during a post-crisis period (Yaakob et al., 2017). The situation in which the approximate element of a soft set cannot be provided with objective evaluations is disregarded (Tao et al., 2015). This study recommended modifying the decision matrix and reflecting uncertain important weights of DMs and criteria (Ran et al., 2008). These studies recommended work in the areas because limited research was found in the literature (Chu and Liu, 2014; Abd et al., 2014). This study recommended that further studies are required to provide an easy-to-use and adjustable model that helps banks identify risks accurately (İç, 2012). In this research, the claim that fuzzy numbers can be generated by using the Rasch model was not only feasible but also corrected the inexactness of fuzzy numbers (Huang and Peng, 2012). In this study, several theories about dual hesitant fuzzy sets were recommended for development (Wang et al., 2014). Another recommendation is the use of FTOPSIS because it is simple and robust in GDM (Afful-Dadzie et al., 2015).

Another type of membership was recommended because the type used in this study may not be suitable for many real-world problems (Mehlawat and Gupta, 2015). Several studies recommended that researchers use the type-2 fuzzy set in future work because it is more flexible and involves more uncertainties than type-1 fuzzy sets (Chen and Hong, 2014a, 2014b; Yaakob et al., 2015; Dymova et al., 2015; Zamri and Abdullah, 2013; Pei, 2013; Solanki et al., 2016; Pei and Zheng, 2010; Chen et al., 2016; Chen and Lee, 2010; Yaakob et al., 2017; Lee and Chen, 2008).

4.3.1.1. Recommendations as limitations of the research. This section presents several limitations encountered by researchers in the related literature. Certain researchers encountered limitations with the accuracy of data because the DMs determined a range of imprecision in the experimental data. A wide range of imprecision can deform the rating of the alternatives (Rudnik and Kacprzak, 2017; Hatami-Marbini and Kangi, 2017). Moreover, when a group of experts is available, varying opinions may appear, thereby resulting in intrinsic cognitive biases and subjectivity in evaluating criteria weights. Such factors cause changes in the results (Li and Chou, 2014; Büyüközkan and Güleryüz, 2015), and pairwise comparisons of DMs are constantly subjective decisions (Wang et al., 2015). Therefore, the accuracy of decision information and the experience of experts still require improved integration into complex decision-making modelling processes (Yaakob et al., 2017). Studies must also focus on the input data quality given by the DMs (Madi et al., 2015). Moreover, a limitation still exists in these studies, in which hybrid criteria values cannot be used (Rao et al., 2015). The proposed method must be improved to support the situations of other information forms, such as numbers or intervals (Fan and Feng, 2009).

Several limitations are related to the number of criteria when including new ones, thereby indicating an exponential increase in decision rules (Osiro et al., 2014) and resulting in a selection process that may be time-consuming and exhausting (Gao et al., 2008). This research was also conducted based on a single company and therefore cannot be circulated to other companies. It did not include the risk factors in SCs (Zhang, 2008). Another limitation is related to the time of data collection because several studies focused on the service quality in hotels, thus indicating that data collection is affected by seasons and, therefore, the result may change (Benitez et al., 2007). This study has a limitation in applying another type of fuzzy sets, such as triangular and trapezoidal fuzzy number, and it applied the interval number only. Moreover, it has several limitations in programming (Yue, 2016; Li and Zhang, 2009). The authors did not include related operations and economic factors (Wang et al., 2015). This study has limitations on the evaluation process of the higher vocational education development level (Li et al., 2016). Most studies also limited the applications of fuzzy set theory to outranking potential suppliers, excluding a qualification stage in the decision process in which non-compensatory types of decision rules can be used to reduce the set of potential suppliers (Lima et al., 2013). In addition, the weakness of this study is related to the fuzzy probabilistic orientation of the alternatives, and the same orientation was performed for the criteria (Bandyopadhyay, 2016).

4.3.1.2. Other recommendation to researchers. In the literature, various papers claimed that the proposed method is simple, effective, feasible, useful and can help DMs in decision making (Rong and FAN, 2009; Wang and Lee, 2009; Tian et al., 2010; Zhang et al., 2015; Huang et al., 2010; Wei and Shengbao, 2008; Yang and Liu, 2016; Guo et al., 2010; Guo and Zhang, 2009; Runqi, 2008; Liao, 2015; Xie et al., 2016; Joshi and Kumar, 2016; Li and Zhao, 2014; İç, 2012; Kelemenis and Askounis, 2009). It is also a flexible and intelligent method for accurately presenting expert data (Yaakob et al., 2015, 2016; Yaakob and Gegov, 2015; Lee and Chen, 2008; Yaakob et al., 2017; Gołuńska et al., 2014). The proposed method has better veracity, feasibility and rationality than the traditional TOPSIS (Liu and Chang, 2010). Thus, this study has a useful impersonation (Lee et al., 2014). This approach can solve complex evaluation problems and is reliable for product development (Geng et al., 2010). DMs may consider additional information to make decisions accurately (Wang et al., 2007). The proposed method can be used with quantitative parameters (La Scalia et al., 2011). This method can also be used to evaluate other MCDMs (Wang and Qin, 2008). In the present study, the proposed algorithm proved useful and exceeded the original FTOPSIS (Aghaie et al., 2011). The network attributes must be denoted by linguistic terms, such as best and better (Liu and Chang, 2010). This study claimed that, when different similarity measures are applied, different rankings of suppliers are derived from those obtained by the distance-based classical TOPSIS (Niyigena et al., 2012). This study contended that the proposed fuzzy MCGDM method can overcome the disadvantages of Chen and Lee's method (Chen and Hong, 2014a). In this work, results show that the network-selected algorithm can select a suitable network for each service (Feng et al., 2016).

4.3.2. Recommendations to governments and managers

This section presents the recommendations found in the related literature to governments and managers.

This study is useful for general managers and DMs because it compares fuzzy utilities in fuzzy decision problems (Javadian et al., 2009). The present study is useful for hospital managers because it can help them improve patient safety (Wang and Chou, 2015). Moreover, this study can help hotel managers understand their relative ranking position and motivate them to increase their quality of service (Benitez et al., 2007). The manufacturing managers of machining centres must support the management of procurement quality and quality control of fittings. Thus, the reliability of their factories can be increased (Shen et al., 2010). This study recommended that the project manager must understand and analyse each task in the project, thereby enabling him/her to evaluate the risk criteria (Zammori et al., 2009).

Several studies recommended that governments oblige organisations to participate in advertising activities to promote the importance of environmentally friendly products. The governments must also invest in science and technology to support environmentally friendly products and develop environmental laws required to force the industry to invest in green technologies. The infrastructure of environmental law enforcement depends on governments. Finally, governments must ensure that environmental laws are implemented in all regions (Mittal and Sangwan, 2014). A study presented a method aligned with government requirements (White and Chandrasekar, 2017). Another study recommended enhancing tourism in East Asia (Huang and Peng, 2012). Finally, a study recommended ways to enhance the ports in Turkey (Celik et al., 2009).

5. Research synthesis

A review of the academic literature published within the scope of this article shows that most of the articles were extended versions of the original TOPSIS using different types of fuzzy memberships. A more beneficial approach would be to look at different versions of TOPSIS, which addressed several issues in the original form (Chen et al., 2011; Kuo, 2017). These articles handled several issues in the original form and produced a more reliable TOPSIS approach.

The other observation is related to the usage of fuzzy classes and types of memberships. Our statistics show that the usage of type-1 fuzzy occupied a larger proportion of the published articles in the academic literature as compared with type-2 fuzzy; however, type-2 fuzzy is more recommended because it produces higher certainty than type-1 fuzzy. In addition, a high-dimension fuzzy corresponds to high certainty. However, more articles extended TOPSIS into a fuzzy environment by using triangular membership rather than trapezoidal membership.

Finally, z-number or fuzzy complex number is utilised in one article. Such limited attempts do not allow readers to conclude for certain whether this type of fuzzy is useful to extend TOPSIS or not.

Given that TOPSIS is a widely used decision-making technique, we still believe a reliable version of fuzzy TOPSIS or group fuzzy TOPSIS requires more intensive research, comparisons and benchmarking process towards achieving this goal.

6. Limitations

This study has several limitations. The first and most important limitation of this work is related to the ScienceDirect database, which cannot show more than 1000 articles. The second limitation is that an article from the WoS database could not be accessed. However, our selected articles can provide an adequate amount for our research topic. The third limitation is related to the rapid growth in this field, which hardly allowed for any timeliness in the survey. The last limitation emphasises that a snapshot of research activity in this energetic direction of decision making does not reflect the reality of MCDM utilisation but reflects only the response of our search in this direction, which is the objective of this study.

7. Conclusion

An important and vital topic for research is decision making. Research on this trend is continuing, and findings remain vague and require further research, although extensive research is available. Information on this trend must also be obtained. This study aims to contribute to such an understanding by inspecting and categorising related studies. From the different works, specific styles can be drawn on the MCDM. These studies are generally classified into four categories, namely, type-1 fuzzy set, type-2 fuzzy set, others and survey paper. An in-depth analysis of the final set of studies can help recognise and describe the motivations and benefits of this topic. The challenges encountered by the researchers and the recommendations related to FMCDM have been discussed. Results indicated the available types of fuzzy numbers used in decision-making applications and the existing gaps in using such applications in FMCDM. Researchers have identified issues and provided recommendations, including the use of fuzzy numbers with MCDM. We also recommended using fuzzy numbers with MCDM to solve vagueness and uncertainty in data because the subjective judgment of experts cannot be easily determined using real numbers. Moreover, TOPSIS has encountered many problems that the researchers can solve in the future. These problems may be solved through normalisation and distance measurement techniques, and the weight of criteria may affect the final selection and aggregation techniques. All these issues provide the researchers with certain reasons to conduct studies in this field in the future. This recommendation can solve challenges encountered by researchers in MCDM. Insights have been provided in this systematic review, and a summary of published studies about FMCDM has been presented. Surveys of these studies may serve well as a reference for scholars in this field. Scholars must continue and implement new studies and learn FMCDM directions. At present, scholars are using FMCDM in different fields to solve many problems.

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