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Supplier evaluation and selection in fuzzy environments: a review of MADM approaches

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ABSTRACT

In past years, the multi-attribute decision-making (MADM) approaches have been extensively applied by researchers to the supplier evaluation and selection problem. Many of these studies were performed in an uncertain environment described by fuzzy sets. This study provides a review of applications of MADM approaches for evaluation and selection of suppliers in a fuzzy environment. To this aim, a total of 339 publications were examined, including papers in peer-reviewed journals and reputable conferences and also some book chapters over the period of 2001 to 2016. These publications were extracted from many online databases and classified in some categories and subcategories according to the MADM approaches, and then they were analysed based on the frequency of approaches, number of citations, year of publication, country of origin and publishing journals. The results of this study show that the AHP and TOPSIS methods are the most popular approaches. Moreover, China and Taiwan are the top countries in terms of number of publications and number of citations, respectively. The top three journals with highest number of publications were: *Expert Systems with Applications*, *International Journal of Production Research* and *The International Journal of Advanced Manufacturing Technology*.

1. Introduction

Supplier evaluation and selection is one of the most important processes to achieve an efficient supply chain. Maintaining long-term partnerships with suppliers and using fewer reliable suppliers can help to increase the value of the supply chain. This is due to the distinct role of suppliers at all stages of the supply chain (Wisner, Tan, & Leong, 2008). Because of the involvement of many factors in the evaluation and selection of suppliers, this problem is usually considered as a multi-attribute decision-making (MADM) problem (Ho, Xu, &

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Dey, 2010; Keshavarz Ghorabaee, Zavadskas, Amiri, & Esmaeili, 2016). MADM problems usually involve discrete decision variables and a limited number of alternatives for evaluation (Buchanan & Vanderpooten, 2007; Liu, Liu, Liu, Zhou, & Zhang, 2015; Oliveira, Fontes, & Pereira, 2015). Uncertainty is an inevitable part of information when the evaluation process is performed by human judgement. The fuzzy set theory is one of the most efficient tools to capture the uncertainty of evaluation processes. Due to this ability of fuzzy sets, many MADM problems have been considered in fuzzy environments. The problem of evaluation and selection of suppliers is one of these MADM problems.

There has been no attempt to review the applications of MADM approaches for fuzzy evaluation and selection of suppliers, although some researchers have published reviews on multi-criteria supplier evaluation and selection (Aissaoui, Haouari, & Hassini, 2007; de Boer, Labro, & Morlacchi, 2001; Govindan, Rajendran, Sarkis, & Murugesan, 2015). Therefore, the main goal of this paper is to review MADM approaches which have been utilised for evaluation and selection in the context of fuzzy sets. This paper also attempts to identify the most prevalent MADM approaches for fuzzy evaluation and selection of suppliers. Moreover, we aim to analyse the articles with respect to their national context, date of publication, number of citations and the journal title.

In this paper, we review a total of 339 scientific articles published in refereed journals and reputable conferences over the period of January 2001 to May 2016. It should be noted that some of the reviewed papers are published as book chapters. Data were sought through various sources including Web of Science, Scopus, EBSCO, ProQuest, IEEE Xplore Digital Library, Scientific.Net, ScienceDirect, Emerald, Springer, Taylor & Francis, CrossRef, DOAJ and ASME. The published papers were reviewed and categorised based on the type of MADM approaches. Some MADM methods used by researchers for fuzzy supplier evaluation and selection are presented in Table 1 with their abbreviations and a brief description. According to these methods and their frequency in the reviewed papers, we classified the

Table 1. Summary of some methods included in the review.

Method	Abbreviation for	Description
AHP	Analytic hierarchy process	Structured technique for analysing MCDM problems according to a pairwise comparison scale.
ANP	Analytic network process	Generalisation of the AHP method which enables the existence of interdependences among criteria.
COPRAS	Complex proportional assessment	Stepwise method aimed to rank a set of alternatives according to their significance and utility degree.
DEA	Data envelopment analysis	Non-parametric system for measuring the efficiency of a set of multiple decision-making units.
EDAS	Evaluation based on distance from average solution	An MADM approach which uses positive and negative distances from the average solution for appraising alternatives.
ELECTRE	Elimination et choix traduisant la realité	Group of techniques addressed to outrank a set of alternatives by determining their concordance and discordance indexes.
MOORA	Multi-objective optimisation by ratio analysis	An outranking method using a ratio system. It became more robust as MULTIMOORA (MOORA plus the full multiplicative form).
PROMETHEE	Preference ranking organisation method for enrichment of evaluations	Family of outranking methods based on the selection of a preference function for each criterion forming a MCDM problem.
TOPSIS	Technique for order of preference by similarity to ideal solution	Technique based on the concept that the best alternative to a MCDM problem is that which is closest to its ideal solution.
VIKOR	Visekriterijumska Optimizacija I kompromisno resenje	Method for determining the compromise ranking-list of a set of alternatives according to the measure of closeness to the ideal solution.
DEMATEL	Decision-making trial and evaluation laboratory	An extended method for building a structural model and analyzing the influence relation among complex criteria.

Source: Authors' conclusions.
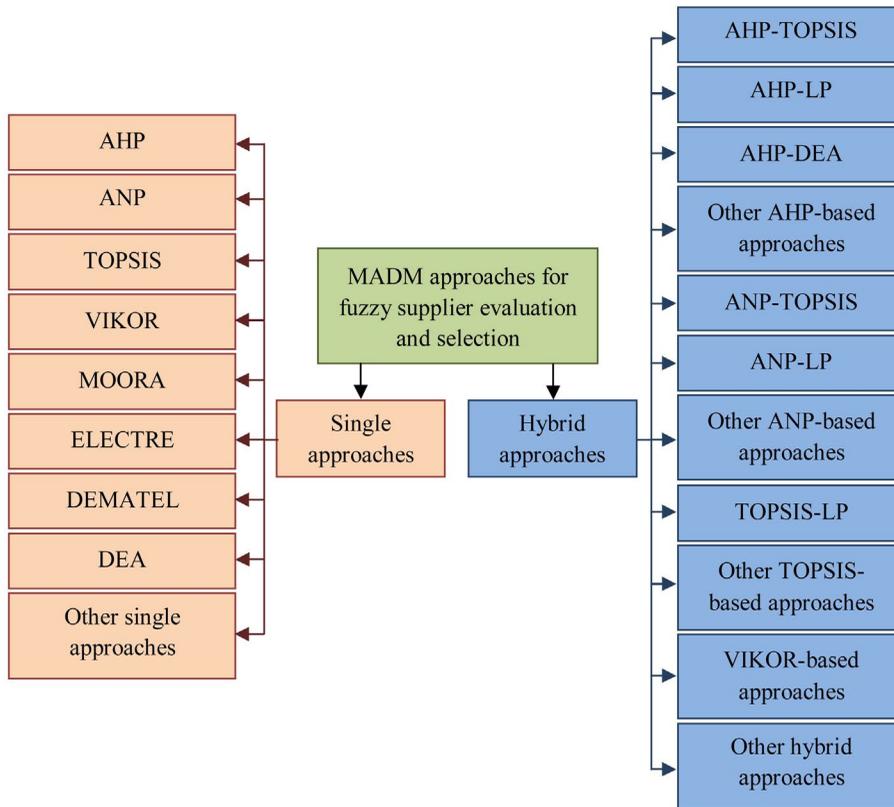
Figure 1. Categories and subcategories for fuzzy supplier evaluation and selection. Source: Authors' scheme.

papers into two main categories. The first category includes papers that applied single MADM approaches and the second category contains articles which used hybrid MADM approaches. Based on the reviewed papers and MADM methods presented in Table 1, we defined some subcategories for these two categories. Figure 1 shows the categorisation considered in this paper. As can be seen, the 'Single approaches' category includes 9 sub-categories and the 'Hybrid approaches' category contains 11 subcategories.

The rest of this paper is organised as follows. In sections 2 and 3, we describe the single and hybrid MADM approaches utilised for fuzzy evaluation and selection of suppliers, respectively. Each of subcategories depicted in Figure 1 has a subsection in section 2 and 3. In section 4, some analyses of the reviewed papers are made to show the most frequent approach, the most influential articles, the national context of articles, the dates of publication and journals publishing in this field. Section 5 provides a discussion about the results of this paper. Conclusions are presented in section 6.

2. Single approaches

In this section, single MADM approaches applied to supplier evaluation and selection in fuzzy environment are reviewed. The AHP, ANP, TOPSIS, VIKOR, DEA, ELECTRE, DEMATEL and MOORA methods, which appear more frequently in the literature, are considered individually, and the other single approaches are reviewed in a separate section.

2.1. AHP

The analytic hierarchy process is a structured MADM method for organising and analysing complex decisions, based on mathematics and psychology. It was developed by Saaty (1990) and has been extensively studied and refined until now. This method has also been popular in the process of supplier evaluation and selection in fuzzy environments. Bottani and Rizzi (2005) proposed a fuzzy multi-attribute framework for supplier selection in an e-procurement environment based on fuzzy AHP, and applied it to an Italian company operating in the food industry. Chan and Kumar (2007) developed a fuzzy extended AHP-based approach for global supplier evaluation considering risk factors. Chan, Kumar, Tiwari, Lau, and Choy (2008) studied the application of the fuzzy AHP to efficiently tackle both quantitative and qualitative decision factors involved in the selection of global suppliers. Lee, Kang, Hsu, and Hung (2009) presented a performance evaluation system based on fuzzy AHP for green suppliers in a high-tech industry. Lee (2009b) proposed a fuzzy AHP model, which incorporates the benefits, opportunities, costs and risks (BOCR) concept, to evaluate various aspects of suppliers for a thin-film-transistor liquid-crystal display (TFT LCD) manufacturer. Aydin and Kahraman (2010) proposed a modified fuzzy AHP and applied it to supplier selection in an air conditioner firm. Kilincci and Onal (2011) investigated supplier selection problem of a well-known washing machine company in Turkey, and a fuzzy analytic hierarchy process-based methodology was used to select the best supplier firm providing the most customer satisfaction for the determined criteria. Koul and Verma (2011) developed a dynamic model based on the fuzzy AHP method to support supplier evaluation and selection in a multi-period planning horizon. T. R. Lee, Phuong Nha Le, Genovese, and Koh (2011) studied factors in green supplier evaluation and used the fuzzy AHP approach to select the most important criteria for green supplier selection in the Taiwanese hand-tool industry. J. Rezaei and Ortt (2013) developed a methodology that includes a fuzzy AHP based on fuzzy preference relations to incorporate the ambiguities and uncertainties which usually exist in human judgement, and applied it to supplier evaluation. Ayhan (2013a) applied the fuzzy AHP approach in a gear motor company for determining the best supplier with respect to some selected criteria. Kaur (2014) proposed an intuitionistic fuzzy analytic hierarchy process for the supplier evaluation and selection problem. Lo and Sudjatmika (2016) developed a new fuzzy analytic hierarchy process method for the efficiency evaluation of suppliers with bell-shaped membership functions. V. Yadav and Sharma (2015) proposed a fuzzy extended analytical hierarchy process approach to select the best supplier in an Indian automobile company using triangular fuzzy numbers. Plebankiewicz and Kubek (2016) described the criteria employed in the evaluation of building material suppliers and applied the fuzzy AHP approach to select the best supplier in this industry.

The abovementioned research only represents some of the important studies that applied AHP approach in the fuzzy environment. Table 2 presents all of the articles where we found the application of the AHP method to fuzzy supplier evaluation and selection as a single approach.

2.2. ANP

The analytic network process or ANP is a more general form of the analytic hierarchy process used in MADM problems. AHP structures a decision problem into a hierarchy with a goal,

Table 2. Publications using the AHP method as a single approach.

No.	Author(s) and year	Type of publication	No.	Author(s) and year	Type of publication
1	Kahraman, Cebeci, and Ulukan (2003)	Journal paper	28	Rahman and Ahsan (2011)	Conference paper
2	Zaim, Sevkli, and Tarim (2003)	Journal paper	29	Cao, Tang, and Xu (2011)	Conference paper
3	Noorul Haq and Kannan (2005)	Journal paper	30	Labib (2011)	Journal paper
4	Bottani and Rizzi (2005)	Journal paper	31	Tang and Fang (2011)	Conference paper
5	Pang (2006)	Conference paper	32	Li, Saadat, and Jules (2012)	Conference paper
6	Cao and Zhou (2006)	Conference paper	33	Xu et al. (2012)	Conference paper
7	Chan and Kumar (2007)	Journal paper	34	Rezaei and Ortt (2013)	Journal paper
8	Benyoucef and Canbolat (2007)	Journal paper	35	Ayhan (2013a)	Journal paper
9	Pang (2007)	Conference paper	36	Jain, Singh, and Mishra (2013)	Journal paper
10	Lu, Wu, and Kuo (2007)	Journal paper	37	Azadnia, Ghadimi, Saman, Wong, and Heavey (2013)	Conference paper
11	Chan et al. (2008)	Journal paper	38	Kar (2013)	Conference paper
12	Hsu, Hu, and Wu (2008)	Conference paper	39	Shaverdi, Heshmati, Eskandaripour, and Tabar (2013)	Conference paper
13	Yang (2008)	Conference paper	40	Ganguly and Guin (2013)	Journal paper
14	Pang (2008a)	Conference paper	41	Kaur (2014)	Journal paper
15	Pang (2008b)	Conference paper	42	Ishizaka (2014)	Journal paper
16	Lee et al. (2009)	Journal paper	43	Cai, Guo, and Zhou (2014)	Conference paper
17	Lee (2009b)	Journal paper	44	Özfirat, Taşoglu, and Memiş (2014)	Journal paper
18	Yang (2009)	Conference paper	45	Jinturkar, Deshmukh, Sarode, Sunapwar, and Khodke (2014)	Book chapter
19	Aydin and Kahraman (2010)	Journal paper	46	Liang (2014)	Conference paper
20	Kahraman and Kaya (2010)	Book chapter	47	Shahraki, Forghani, Kalantari, and Estanesti (2014)	Journal paper
21	Tseng, Su, and Huang (2010)	Conference paper	48	Aggarwal and Sharma (2014)	Conference paper
22	Kilincci and Onal (2011)	Journal paper	49	Lo and Sudjatmika (2016)	Journal paper
23	Koul and Verma (2011)	Journal paper	50	Yadav and Sharma (2015)	Journal paper
24	Lee et al. (2011)	Journal paper	51	Nikou and Moschuris (2015)	Book chapter
25	Çifçi and Büyüközkan (2011)	Journal paper	52	Xiong, Chen, Shang, Liu, and Nyberg (2015)	Conference paper
26	Costantino, Dotoli, Falagario, and Fanti (2011)	Journal paper	53	Plebankiewicz and Kubek (2016)	Journal paper
27	Aktepe and Ersoz (2011)	Journal paper			

Source: Authors' calculations.

decision criteria and alternatives, while the ANP structures it as a network (Saaty, 1996). This method is one of the MADM approaches which have been used for fuzzy supplier evaluation and selection. Razmi, Rafiei, and Hashemi (2009) developed a fuzzy analytic network process model to evaluate the potential suppliers and select the best one with respect to some important factors. B. Pang (2009) proposed a supplier evaluation approach based on the fuzzy ANP and fuzzy synthetic evaluation. Instead of the classical eigenvector prioritisation method, employed in the prioritisation stage of the ANP, a fuzzy preference programming method was applied in his approach. Kang, Lee, and Yang (2010) presented a fuzzy ANP model for supplier selection and applied it to selection of most appropriate IC packaging supplier for a Taiwanese semiconductor manufacturer. X. Chen and Hu (2010) studied the application of the fuzzy analytic network process in supplier selection based on the connection number. Vinodh, Anesh Ramiya, and Gautham (2011) used the fuzzy ANP approach for the supplier selection process in an Indian electronics switches manufacturing company. B. Pang and Bai (2011) developed an integrated fuzzy ANP and fuzzy synthetic evaluation methodology for evaluating and selecting the most suitable suppliers. Gülçin Büyüközkan and Çifçi (2012a) proposed an MADM approach based on fuzzy ANP for evaluation of green supply chain management practices. Dargi, Anjomshoae, Galankashi, Memari, and Tap (2014) presented a framework comprising the most critical factors for supplier selection in the automotive industries and used the fuzzy ANP to weight the extracted measures and determine their importance level. X. Zhang, Deng, Chan, and Mahadevan (2015) proposed a fuzzy extended analytic network process-based approach for global supplier selection. Xu, Elomri, Pokharel, and Ming (2015) developed a modified fuzzy ANP to reduce decision information distortion in product–service supplier pre-evaluation processes. J. Wei and Sun (2009) and J. Y. Wei, Sun, and Wang (2010) also used the fuzzy ANP approach for the supplier evaluation and selection problem.

2.3. TOPSIS

The TOPSIS method is an MADM approach, which was originally developed by Hwang and Yoon (1981). TOPSIS is based on the concept that the chosen alternative should have the shortest distance from the positive ideal solution (PIS) and the longest distance from the negative ideal solution (NIS). This method has been very useful in the evaluation and selection of suppliers in fuzzy environments. Boran, Genç, Kurt, and Akay (2009) proposed a fuzzy MADM approach for supplier selection based on the TOPSIS method and intuitionistic fuzzy sets. Awasthi, Chauhan, and Goyal (2010) presented a fuzzy multi-attribute approach based on the TOPSIS method for evaluating the environmental performance of suppliers. Y. Deng and Chan (2011) employed the fuzzy set theory and Dempster Shafer theory of evidence, and developed a TOPSIS-based approach for supplier selection. Luukka (2011) used the fuzzy similarity and the TOPSIS method for supplier evaluation and selection in supply chain management. Izadikhah (2012) proposed a TOPSIS method under interval-valued intuitionistic fuzzy numbers for supplier selection. Yayla, Yildiz, and Ozbek (2012) applied the fuzzy TOPSIS method for supplier selection in the garment industry. Roshandel, Miri-Nargesi, and Hatami-Shirkouhi (2013) presented a hierarchical fuzzy TOPSIS for evaluating and selecting the supplier in the detergent production industry. L. Shen, Olfat, Govindan, Khodaverdi, and Diabat (2013) proposed a fuzzy multi-attribute approach for evaluating green suppliers' performance in a green supply chain using the

Table 3. Publications using the TOPSIS method as a single approach.

No.	Author(s) and year	Type of publication	No.	Author(s) and year	Type of publication
1	Chen, Lin, and Huang (2006)	Journal paper	22	Roshandel et al. (2013)	Journal paper
2	Wang, Chen, and Chen (2007)	Conference paper	23	Shen et al. (2013)	Journal paper
3	Wang and Wei (2008)	Conference paper	24	Wu, Lin, and Kung (2013)	Journal paper
4	Xiao and Wei (2008)	Conference paper	25	Ayhan (2013b)	Journal paper
5	Tang, Liang, Ding, Shu, and Wang (2008)	Conference paper	26	Wen, Xu, and Wang (2013)	Journal paper
6	Boran et al. (2009)	Journal paper	27	Kannan et al. (2014)	Journal paper
7	Sreekumar (2009)	Journal paper	28	Tadić et al. (2014)	Journal paper
8	Kavita, Yadav, and Kumar (2009)	Conference paper	29	Zhao and Guo (2014)	Journal paper
9	Wang, Lee, and Cheng (2009)	Conference paper	30	Djordjevic et al. (2014)	Journal paper
10	Awasthi et al. (2010)	Journal paper	31	Roghanian et al. (2014)	Journal paper
11	Guo, Meiran, and Xin (2010)	Conference paper	32	Eslamian Shiraz, Şengül, and Eren (2014)	Journal paper
12	Sevkli, Zaim, Turkyilmaz, and Satir (2010)	Conference paper	33	Otheman, Ghani, and Abdullah (2014)	Conference paper
13	Deng and Chan (2011)	Journal paper	34	Dowlatshahi et al. (2015)	Journal paper
14	Luukka (2011)	Journal paper	35	M. Li and Wu (2015)	Journal paper
15	Zarbini-Sydani, Karbasi, and Atef-Yekta (2011)	Journal paper	36	Lima Junior and Carpinetti (2015)	Journal paper
16	Izadikhah (2012)	Journal paper	37	Li and Wang (2015)	Journal paper
17	Yayla et al. (2012)	Journal paper	38	Venkatesh et al. (2015)	Journal paper
18	Kiliç (2012)	Journal paper	39	Awasthi (2015)	Book chapter
19	Niyigena, Luukka, and Collan (2012)	Conference paper	40	Chatterjee and Kar (2016)	Journal paper
20	Qiansheng Zhang and Huang (2012)	Conference paper	41	Sahu et al. (2016)	Journal paper
21	Y. J. Wang, Han, and Kao (2012)	Conference paper			

Source: Authors' calculations.

TOPSIS method and linguistic preferences. Kannan, Jabbour, and Jabbour (2014) applied the fuzzy TOPSIS method for selecting green suppliers with respect to the green supply chain management (GSCM) practices in a Brazilian electronics company. Tadić, Stefanović, and Aleksić (2014) proposed a fuzzy TOPSIS method for evaluation and ranking of medical device suppliers. Zhao and Guo (2014) developed a fuzzy TOPSIS method based on entropy weighting and applied it to selecting green suppliers of thermal power equipment. Djordjevic, Puskaric, and Djordjevic (2014) proposed a fuzzy TOPSIS for evaluation of hip prosthesis suppliers. Roghanian, Sheykhan, and Sayyad Abendankashi (2014) applied the fuzzy TOPSIS approach for supplier evaluation in the food industry. Dowlatshahi, Karimi-Nasab, and Bahrololum (2015) developed a group decision-making approach for supplier selection in configuration design based on fuzzy TOPSIS. M. Li and Wu (2015) proposed an improved TOPSIS method with intuitionistic fuzzy sets for green supplier selection. Chatterjee and Kar (2016) developed an interval valued fuzzy TOPSIS for supplier evaluation in electronics supply chains with respect to risk-based criteria. Sahu, Sahu, and Sahu (2016) proposed a modified interval-valued fuzzy TOPSIS method for selection of appropriate suppliers in an agile supply chain. Some other studies also used the TOPSIS approach as a single approach in the process of fuzzy supplier evaluation and selection. We present all of the publications of this subcategory in Table 3.

2.4. VIKOR

The VIKOR method is an MADM approach proposed by Opricovic (1998). Like many MADM methods, this method has also been extended for dealing with fuzzy decision-making

problems. Supplier evaluation and selection is one of the problems that the VIKOR method has been applied to. G. Büyüközkan and Feyzioğlu (2008) extended the original VIKOR method for evaluation of suppliers' environmental management performances in a fuzzy environment. Sanayei, Farid Mousavi, and Yazdankhah (2010) proposed a hierarchical MADM model based on the fuzzy sets theory and VIKOR method to deal with supplier selection problems in the supply chain system. Shemshadi, Shirazi, Toreihi, and Tarokh (2011) employed Shanon entropy to extend the VIKOR method and applied it to fuzzy evaluation of suppliers. Amiri, Ayazi, Olfat, and Moradi (2011) applied the fuzzy VIKOR method for fuzzy evaluation and selection of auto parts suppliers in Iran. Roostaee, Izadikhah, Lotfi, and Rostamy-Malkhalifeh (2012) extended the VIKOR method for group decision-making with intuitionistic fuzzy numbers to solve the supplier selection problem under incomplete and uncertain information. Mozafari, Asli, and Khanghah (2012) provided a model for selecting a suitable outsourcing supplier based on the fuzzy VIKOR method. Wu and Geng (2014) proposed an MADM approach for evaluation of coal suppliers based on intuitionistic fuzzy sets and the VIKOR method. You, You, Liu, and Zhen (2015) developed a group multi-attribute supplier selection framework using an extended VIKOR method with interval 2-tuple linguistic information. Reza Rostamzadeh, Govindan, Esmaeili, and Sabaghi (2015) applied the fuzzy VIKOR method for evaluation of suppliers with respect to green supply chain management practices. Sahu, Datta, and Mahapatra (2016) used the VIKOR method for evaluation and selection of resilient suppliers in fuzzy environments.

2.5. MOORA

The MOORA method is an efficient MADM method which was proposed by Brauers and Zavadskas (2006) and extended to the MULTIMOORA (MOORA plus the full multiplicative form) by Brauers and Zavadskas (2010). This method has been applied to many real-world MADM problems in certain and uncertain environments. Some researchers have also used the MOORA method for fuzzy supplier evaluation and selection problems. Baležentis and Baležentis (2011) developed an innovative multi-attribute supplier selection approach based on 2-tuple MULTIMOORA and hybrid data. Dey, Bairagi, Sarkar, and Sanyal (2012) proposed an extended fuzzy MOORA method for supplier evaluation and selection problems. Pérez-Domínguez, Alvarado-Iniesta, Rodríguez-Borbón, and Vergara-Villegas (2015) developed a fuzzy MADM approach for evaluation and selection of suppliers based on intuitionistic fuzzy MOORA. S. Mishra, Sahu, Datta, and Mahapatra (2015) presented the application of a fuzzy integrated MULTIMOORA method for supplier and partner selection in an agile supply chain.

2.6. ELECTRE

The ELECTRE method was first proposed by Roy (1968) and has been extended to some versions like ELECTRE II, ELECTRE III, ELECTRE IV, ELECTRE IS and ELECTRE TRI (Govindan & Jepsen, 2016a). Extended fuzzy versions of the ELECTRE method have been applied to fuzzy supplier evaluation and selection in some studies until now. Montazer, Saremi, and Ramezani (2009) designed a new mixed expert decision aiding system using the fuzzy ELECTRE III method for supplier evaluation and selection. Mehmet Sevkli (2010)

compared the results of the crisp and fuzzy ELECTRE methods for supplier selection in a manufacturing company in Turkey. Fahmi, Kahraman, and Bilen (2016) extended the ELECTRE I method with hesitant linguistic term sets and applied it to the supplier selection problem. Govindan and Jepsen (2016b) proposed an MADM approach based on trapezoidal intuitionistic fuzzy numbers and ELECTRE TRI-C for service supplier risk assessment.

2.7. DEMATEL

The DEMATEL method was first conducted by the Battelle Memorial Institute through its Geneva Research Centre (Gabus & Fontela, 1972). DEMATEL is an extended method for building and analysing a structural model for analysing the influence relation among complex criteria. This method has been used in some studies for evaluation of suppliers in a fuzzy environment. Chang, Chang, and Wu (2011) used the DEMATEL method to evaluate supplier performance and find key factor criteria for improving performance, and provided a novel approach of decision-making in supply chain management (SCM) supplier selection. R.-J. Lin (2013) examined the influential factors among some criteria of three main GSCM practices, namely practices, performances, and external pressures by using fuzzy DEMATEL. Reza Kiani Mavi, Kazemi, Najafabadi, and Mousaabadi (2013) developed a framework for identification and assessment of logistical factors to evaluate green suppliers using the fuzzy DEMATEL method. Routroy and Sunil Kumar (2014) proposed a methodology to identify, quantify and establish relationships (i.e. cause and effect) among various supplier development programme enablers in an Indian manufacturing company. R. K. Mavi and Shahabi (2015) applied the fuzzy DEMATEL method for evaluating supplier selection criteria in manufacturing industries.

2.8. DEA

Data envelopment analysis is a linear programming (LP) methodology to measure the efficiency of multiple decision-making units (DMUs) when the process presents a structure of multiple inputs and outputs. The fuzzy DEA method has been widely used in various types of problems (Hatami-Marbini, Emrouznejad, & Tavana, 2011). Some studies have also been performed by applying this method to the process of supplier evaluation and selection with fuzzy data. Azadeh, Alem, Nazari-Shirkoohi, and Rezaie (2009) performed a Monte Carlo simulation analysis of DEA, fuzzy DEA and chance constraint DEA for supplier selection problems in the supply chain and presented a decision-making plan for choosing the appropriate model. Azadeh and Alem (2010) proposed flexible deterministic, stochastic and fuzzy DEA approaches for supply chain risk and supplier selection problems. Costantino, Dotoli, Epicoco, Falagario, and Sciancalepore (2012b) developed a novel fuzzy data envelopment analysis methodology for performance evaluation of suppliers in a two-stage supply chain. Costantino, Dotoli, Epicoco, Falagario, and Sciancalepore (2012a) presented a cross-efficiency fuzzy data envelopment analysis technique for supplier evaluation under uncertainty and applied it to an Italian small and medium-sized enterprise (SME) case study. Ahmady, Azadi, Sadeghi, and Saen (2013) proposed a novel fuzzy data envelopment analysis model with double frontiers for supplier selection problems. A. Amindoust, Ahmed, and Saghafinia (2013) applied the data envelopment analysis for green supplier selection in manufacturing under fuzzy environments. Atefeh Amindoust and Saghafinia (2014) proposed a fuzzy DEA approach based on alpha cuts

for supplier selection. Azadi, Jafarian, Farzipoor Saen, and Mirhedayatian (2015) developed a new fuzzy DEA model for evaluation of the efficiency and effectiveness of suppliers in the sustainable supply chain management context.

2.9. Other single approaches

In addition to the single approaches stated in previous sections, some other methods have also been applied to supplier evaluation and selection problems in the fuzzy environment. Some of these single approaches only use simple fuzzy methods, and some others developed an extended fuzzy approach. Chou and Chang (2008) and Sandeep, Kumanan, and Vinodh (2011) applied the fuzzy simple multi-attribute rating technique (SMART) approach for supplier selection. W.-P. Wang (2010) proposed a fuzzy linguistic computing approach for supplier evaluation. Lam, Tao, and Lam (2010) presented a material supplier selection model for property developers using fuzzy principal component analysis (PCA). Aydın Keskin, İlhan, and Özkan (2010) developed a categorisation method for supplier evaluation and selection based on the fuzzy adaptive resonance theory algorithm. B.-M. Hsu, Chiang, and Shu (2010) proposed a method for supplier selection using fuzzy quality data. Vahdani and Zandieh (2010) introduced a new fuzzy multi-criteria decision model based on the fuzzy balancing and ranking method. Tan, Wu, and Ma (2011) developed a model for supplier selection using fuzzy measures and linguistic preference relations. Wibowo (2011) proposed a fuzzy multi-attribute group decision-making approach for improving the degree of confidence in supplier selection. Chu and Varma (2012) presented a multiple-level multi-criteria decision-making method for evaluating suppliers. Ferreira and Borenstein (2012) proposed a fuzzy-Bayesian model for supplier selection. Atefeh Amindoust, Ahmed, Saghafinia, and Bahreininejad (2012) developed a ranking model based on a fuzzy inference system for sustainable supplier selection. García, Puente, Fernández, and Priore (2013) proposed a fuzzy decision support system for supplier selection of commodities procurement. Nourianfar and Montazer (2013) developed a fuzzy MADM approach based on the COPRAS method to solve supplier selection problems. Kumar, Singh, Singh, and Seema (2013) proposed a fuzzy logic-based decision support system for evaluation of suppliers in supply chain management practices. Zhang et al. (2013) and Bai, Li, and Yang (2014) presented two dynamic fuzzy group decision-making approaches for supplier selection. Senvar, Tuzkaya, and Kahraman (2014) proposed a multi-attribute supplier selection approach using the fuzzy PROMETHEE method. Lee and Omar (2014) and Kannan, Govindan, and Rajendran (2015) used the fuzzy axiomatic approach for supplier selection. Yu, Li, and Merigó (2016) developed a dual hesitant fuzzy group decision-making method and applied it to the supplier selection problem. Chai and Ngai (2015) proposed a soft decision model for multi-perspective strategic supplier selection based on hesitant fuzzy sets. Davis, Shipley, and Stading (2015) presented a fuzzy supplier selection model using large survey datasets of delivery performance. Yu (2015) applied the triangular Atanassov's intuitionistic fuzzy Bonferroni mean to supplier selection. Tosun and Akyüz (2015) developed a fuzzy TODIM (an acronym in Portuguese for iterative multi-criteria decision making) approach for the supplier selection problem. Xu, Patnayakuni, Tao, and Wang (2015) utilised the incomplete interval fuzzy preference relations for supplier selection in supply chain management. Qin and Liu (2016) presented an MADM approach based on the 2-tuple linguistic Muirhead mean and applied it to the supplier evaluation process. Ghorabaee, Zavadskas, Amiri, and Turskis (2016) developed an

extended EDAS method for fuzzy multi-attribute supplier selection. Heidarzade, Mahdavi, and Mahdavi-Amiri (2016) proposed a clustering method for supplier selection problems based on a new distance measure for interval type-2 fuzzy sets. We also found some other studies which used single approaches for evaluation and selection of suppliers in a fuzzy environment. Table 4 represents all of the reviewed publications in this subcategory with their approaches.

3. Hybrid approaches

In this section, we categorise the hybrid MADM approaches which were utilised for the process of evaluation and selection of suppliers in fuzzy environments. This categorisation is based on the popularity of the approaches, and some hybrid approaches which have less frequency in the literature are categorised in a separate section.

3.1. AHP–TOPSIS

Many studies have used a combination of the AHP and TOPSIS methods for fuzzy supplier evaluation and selection. Wang, Cheng, and Huang (2009) proposed a fuzzy hierarchical TOPSIS for supplier selection based on fuzzy TOPSIS and fuzzy AHP methods. Gnanasekaran, Velappan, and Manimaran (2010) developed an integrated model for supplier evaluation in a steel plant based on fuzzy AHP and TOPSIS methods. Chen and Yang (2011) proposed a new method for multi-attribute group decision-making which uses a constrained fuzzy analytic hierarchy process to measure the relative importance of attributes and a fuzzy TOPSIS to rank the alternatives. Zeydan, Çolpan, and Çobanoğlu (2011) developed a two-stage MADM approach for selecting suitable supplier(s) in an automotive factory in Turkey by using fuzzy AHP, fuzzy TOPSIS and DEA methods. Wittstruck and Teuteberg (2011) presented an integrated fuzzy AHP–TOPSIS approach for sustainable supplier selection in the electrics and electronics industry. Zouggari and Benyoucef (2012) applied fuzzy AHP and a simulation-based fuzzy TOPSIS for the evaluation and selection of suppliers. Li, Liu, and Chen (2012b) used axiomatic fuzzy set clustering to cluster the potential suppliers and employed fuzzy AHP and TOPSIS methods to select the best suppliers. Gülçin Büyüközkan (2012) applied the fuzzy AHP, fuzzy axiomatic design and fuzzy TOPSIS approaches for green supplier evaluation processes. Muralidhar, Ravindranath, and Srihari (2012) developed an MADM approach for evaluation of green supply chain management strategies using fuzzy AHP and TOPSIS. Wittstruck and Teuteberg (2012) proposed a fuzzy AHP–TOPSIS approach for integrating the concept of sustainability into the partner selection process. Ghorbani, Mohammad Arabzad, and Shahin (2013) presented a novel approach for supplier selection based on the Kano model, fuzzy analytic hierarchy process and fuzzy TOPSIS. Lima Junior, Osiro, and Carpinetti (2014) performed a comparison between fuzzy AHP and fuzzy TOPSIS methods for supplier evaluation and selection. Asemi, Baba, and Asemi (2014) employed the fuzzy analytic hierarchy process, fuzzy inference system (FIS) and fuzzy TOPSIS approaches for supplier selection in a steel company. Rostamzadeh (2014) used the fuzzy AHP and TOPSIS methods for evaluation of criteria and selection of suppliers in a tractor manufacturing company. Yazdani (2014) presented an integrated fuzzy AHP–TOPSIS approach for green supplier selection in an automobile manufacturing supply chain. Lee, Cho, and Kim (2015) applied fuzzy AHP and TOPSIS

Table 4. Publications using the other single approaches.

No.	Author(s) and year	Type of publication	Approach used
1	Altinoz and Winchester (2001)	Journal paper	A fuzzy logic-based approach
2	Maurizio Bevilacqua and Petroni (2002)	Journal paper	A fuzzy logic-based approach
3	Bayrak, Çelebi, and Taşkin (2007)	Journal paper	A fuzzy logic-based approach
4	Song, Zhang, and Zhou (2007)	Conference paper	An approach based on intuitionistic fuzzy sets
5	Chou and Chang (2008)	Journal paper	Fuzzy SMART approach
6	Ordoobadi (2009)	Journal paper	A fuzzy logic-based approach
7	Guneri and Kuzu (2009)	Journal paper	A fuzzy logic-based approach
8	Guozheng (2009)	Conference paper	A fuzzy logic-based approach
9	Wang and Zhang (2009)	Conference paper	A fuzzy logic-based approach
10	Wang (2010)	Journal paper	Fuzzy linguistic computing approach
11	Lam et al. (2010)	Journal paper	Fuzzy principal component analysis
12	Aydın Keskin et al. (2010)	Journal paper	Fuzzy adaptive resonance theory
13	Hsu et al. (2010)	Journal paper	Fuzzy quality data
14	Vahdani and Zandieh (2010)	Journal paper	Fuzzy balancing and ranking
15	Chen, Wang, and Lu (2011)	Journal paper	An approach based on intuitionistic fuzzy sets
16	Zhang (2011)	Conference paper	An approach based on intuitionistic fuzzy sets
17	Li, Yue, and Zhou (2011)	Journal paper	An approach based on intuitionistic fuzzy sets
18	Sandeep et al. (2011)	Journal paper	Fuzzy SMART approach
19	Tan et al. (2011)	Journal paper	Linguistic preference relations
20	Wibowo (2011)	Conference paper	An approach based on the positive and negative ideal
21	Shohaimay, Ramli, and Mohamed (2012)	Conference paper	A fuzzy logic-based approach
22	Zhang, Jiang, and Huang (2012)	Journal paper	An approach based on intuitionistic fuzzy sets
23	Khaleie, Fasanghari, and Tavassoli (2012)	Journal paper	An approach based on intuitionistic fuzzy sets
24	Chai, Liu, and Xu (2012)	Journal paper	An approach based on intuitionistic fuzzy sets
25	Humaira and Bambang (2012)	Conference paper	An approach based on interval type-2 fuzzy sets
26	Chu and Varma (2012)	Journal paper	Multiple levels approach
27	Ferreira and Borenstein (2012)	Journal paper	Fuzzy-Bayesian model
28	Atefeh Amindoust et al. (2012)	Journal paper	Fuzzy inference system
29	Shan (2012)	Journal paper	A fuzzy logic-based approach
30	Shen and Yu (2012)	Journal paper	A fuzzy logic-based approach
31	Shahgholian, Shahraki, Vaezi, and Hajihosseini (2012)	Journal paper	A fuzzy logic-based approach
32	Pattnaik (2013)	Journal paper	A fuzzy logic-based approach
33	Mirjani, Wahab, and Li (2013)	Conference paper	An approach based on intuitionistic fuzzy sets
34	Tuzkaya (2013)	Journal paper	An approach based on intuitionistic fuzzy sets
35	Wang, Zeng, and Zhang (2013)	Journal paper	An approach based on intuitionistic fuzzy sets
36	Gong (2013)	Journal paper	An approach based on interval type-2 fuzzy sets
37	García et al. (2013)	Journal paper	Fuzzy decision support system
38	Nourianfar and Montazer (2013)	Conference paper	Fuzzy COPRAS

39	Darshan Kumar et al. (2013)	Journal paper	Fuzzy decision support system
40	Zhang et al. (2013)	Journal paper	Dynamic fuzzy group decision-making
41	Osiro, Lima-Junior, and Carpinetti (2014)	Journal paper	A fuzzy logic-based approach
42	Kumar Sahu, Datta, and Sankar Mahapatra (2014)	Journal paper	A fuzzy logic-based approach
43	Keshavarz Ghorabaee, Amiri, Salehi Sadaghiani, and Hassani Goodarzi (2014)	Journal paper	An approach based on interval type-2 fuzzy sets
44	Bai et al. (2014)	Conference paper	Dynamic fuzzy group decision-making
45	Senvar et al. (2014)	Book chapter	Fuzzy PROMETHEE
46	Lee and Omar (2014)	Conference paper	Fuzzy axiomatic approach
47	Qiao, Shi, and Fu (2015)	Conference paper	A fuzzy logic-based approach
48	Paul (2015)	Journal paper	A fuzzy logic-based approach
49	Kar and Chatterjee (2015)	Conference paper	An approach based on interval type-2 fuzzy sets
50	Kannan et al. (2015)	Journal paper	Fuzzy axiomatic approach
51	Yu et al. (2016)	Journal paper	Dual hesitant fuzzy group decision-making
52	Chai and Ngai (2015)	Journal paper	Soft decision model
53	Davis et al. (2015)	Journal paper	Fuzzy Preference Algorithm
54	Yu (2015)	Journal paper	Intuitionistic fuzzy Bonferroni mean
55	Tosun and Akyüz (2015)	Journal paper	Fuzzy TODIM
56	Xu et al. (2015)	Journal paper	Interval fuzzy preference relations
57	Qin, Liu, and Pedrycz (2016)	Journal paper	An approach based on interval type-2 fuzzy sets
58	Keshavarz Ghorabaee, Zavadskas, Amiri, and Antucheviciene (2016)	Journal paper	An approach based on interval type-2 fuzzy sets
59	Qin and Liu (2016)	Journal paper	2-tuple linguistic approach
60	Ghorabaee et al. (2016)	Journal paper	Fuzzy EDAS
61	Heidarzade et al. (2016)	Journal paper	Interval type-2 clustering

Source: Authors' calculations.

approaches for assessing the business impacts of agility criterion and order allocation strategies in a multi-attribute supplier selection process. Beikkhakhian, Javanmardi, Karbasian, and Khayambashi (2015) developed a model based on interpretive structural model (ISM) and fuzzy TOPSIS–AHP methods for evaluating agile supplier selection criteria and ranking suppliers. Bronja and Bronja (2015) proposed a two-phase selection procedure of an aluminised sheet supplier by applying fuzzy AHP and fuzzy TOPSIS methodology. Sultana, Ahmed, and Azeem (2015) developed an integrated approach for multi-attribute supplier selection using fuzzy Delphi, fuzzy AHP and fuzzy TOPSIS approaches. Wang Chen, Chou, Luu, and Yu (2016) presented a fuzzy MADM approach for green supplier selection with respect to economic and environmental criteria by using the AHP and TOPSIS methods. This hybrid approach was also applied in the research of Tadic, Milanovic, Misita, and Tadic (2011), Bhayana, Kaur, and Jha (2015) and Hamdan and Cheaitou (2015).

3.2. AHP–LP

Combination of the AHP method with linear programming is another hybrid approach utilised by researchers for fuzzy supplier evaluation and selection. Kumar, Shankar, and Yadav (2008) proposed an integrated approach using an analytic hierarchy process and fuzzy linear programming for supplier selection and order allocation problems. Sevkli, Lenny Koh, Zaim, Demirbag, and Tatoglu (2008) applied integration of the AHP method and fuzzy linear programming for supplier evaluation in a Turkish appliance manufacturer. T.-Y. Wang and Yang (2009) used the analytic hierarchy process and fuzzy compromise programming and proposed multi-objective linear programming for supplier selection in quantity discount environments. Chamodrakas, Batis, and Martakos (2010) developed a two-stage approach based on fuzzy AHP and a modified variant of the fuzzy preference programming (FPP) method. Şen, Şen, and Başlıgil (2010) presented an approach for selection of suppliers through an integrated fuzzy AHP and max–min linear programming. Shaw, Shankar, Yadav, and Thakur (2012) proposed a supplier selection model based upon fuzzy AHP and fuzzy multi-objective linear programming for developing a low carbon supply chain. Kannan, Khodaverdi, Olfat, Jafarian, and Diabat (2013) developed an integrated fuzzy MADM approach using AHP and multi-objective programming for supplier selection and order allocation in a green supply chain. Perić, Babić, and Veža (2013) presented a hybrid approach for supplier selection and supply quantities determination in a bakery based on AHP and fuzzy linear programming. . Shaw, Shankar, Yadav, and Thakur (2013) integrated the AHP and multi-objective fuzzy linear programming approaches for global supplier selection considering sustainability and carbon footprint issues. Kar (2014) developed a two-stage multi-attribute model for supplier selection using fuzzy AHP and fuzzy goal programming. Amir Hossein Azadnia, Saman, and Wong (2014) proposed an integrated multi-objective decision-making process for sustainable supplier selection and order lot-sizing based on fuzzy AHP and linear programming. Liao, Fu, and Wu (2016) presented an integrated MADM approach using fuzzy AHP, fuzzy ARAS and multi-segment goal programming for green supplier evaluation and selection. Han, Luo, Chen, and Yang (2015) proposed an integrated MADM approach based on the AHP method and fuzzy zero-one programming for supplier evaluation. Ulutas, Shukla, Kiridena, and Gibson (2016) proposed a utility-driven approach to supplier evaluation and selection based on fuzzy AHP, fuzzy COPRAS and linear programming, and applied it to a Turkish textile company. Asgari,

Abbasi, and Alimohamadlou (2016) compared the integrated fuzzy AHP-goal programming approach with the adaptive neuro-fuzzy inference system (ANFIS) method for supplier selection problems. Kumar, Rahman, and Chan (2017) developed a fuzzy AHP and fuzzy multi-objective linear programming model for supplier evaluation and order allocation in a sustainable supply chain and applied it to an Indian automobile company. Some other researchers also utilised this hybrid approach in their studies (Kenarroudi, 2012; Ketata, Ben Mahmoud, & Romdhan, 2008; Ku, Chang, & Ho, 2009).

3.3. AHP–DEA

Some researchers have used the integration of the AHP with data envelopment analysis for evaluation and selection of suppliers in fuzzy environments. Yuan, Liu, Tu, and Xue (2008) presented a hybrid approach by modifying DEA and using fuzzy AHP for evaluation of suppliers. Kuo, Lee, and Hu (2010) developed a supplier selection system through integrating fuzzy AHP and fuzzy DEA and applied it to an auto-lighting system company in Li, Liu, and Chen (2012a) proposed an integrated MADM approach to supplier evaluation using fuzzy axiomatic clustering, fuzzy AHP and DEA methods. Awasthi, Noshad, and Chauhan (2014) proposed an integrated approach for supplier performance evaluation based on Delphi, AHP and fuzzy DEA. Yadav and Sharma (2015) presented a supplier selection procedure in an automobile company based on AHP, the data envelopment analytic hierarchy process and fuzzy AHP approaches.

3.4. Other AHP-based approaches

The AHP method has been integrated with some other approaches by researchers for fuzzy supplier evaluation and selection. Kong, Zhang, and Liu (2008) proposed an integrated approach based on the fuzzy AHP and grey relation model for logistics supplier evaluation. Zhongwei and Jianzhong (2008a) presented a decision model for supplier selection in a SCM based on the AHP and fuzzy comprehensive evaluation. Cheng and Tang (2009) proposed an MADM approach by integration of fuzzy Delphi and fuzzy AHP for supplier evaluation in bicycle industry supply chains. Deng and Hu (2010) integrated the ELECTRE method with fuzzy AHP and applied it to supplier selection in an airline company. Yücenur, Vayvay, and Demirel (2011) presented an approach based on fuzzy AHP and fuzzy ANP methods for selection of the best supplier in a global supply chain. Ertay, Kahveci, and Tabanlı (2011) developed a model for evaluating and monitoring suppliers' performance using fuzzy analytic hierarchy process and ELECTRE III methods. Azadnia, Ghadimi, Mat Saman, Wong, and Sharif (2011) proposed an integrated approach based on fuzzy AHP, ELECTRE and fuzzy c-mean (FCM) clustering methods. Raut, Bhasin, and Kamble (2011) proposed a new approach for evaluation of supplier selection criteria by a combination of AHP and fuzzy DEMATEL methods. Li, Wong, and Kwong (2013) developed an integrated model of material supplier selection and order allocation using extended fuzzy AHP and dynamic programming. Alinezad, Seif, and Esfandiari (2013) presented a supplier evaluation and selection approach using quality function deployment (QFD) and fuzzy AHP, and applied it to a pharmaceutical company. Pitchipoo, Venkumar, and Rajakarunakaran (2013) proposed an integrated decision model for evaluating suppliers by combining the fuzzy analytic hierarchy process and grey relational analysis. Rezaei, Fahim, and Tavasszy (2014)

developed a decision-making approach for supplier selection in the airline retail indus-try based on the conjunctive screening method and fuzzy AHP. Hashemian, Behzadian, Samizadeh, and Ignatius (2014) proposed a fuzzy hybrid group decision support system approach to supplier evaluation using fuzzy AHP and fuzzy PROMETHEE methods. Kar (2015) presented a hybrid group decision support system for supplier selection using the analytic hierarchy process, fuzzy set theory and neural network. Wang (2015) proposed an integrated MADM approach based on QFD, fuzzy Delphi, fuzzy DEMATEL and fuzzy AHP methods for supplier evaluation. Mavi (2015) developed a hybrid method using fuzzy AHP and fuzzy ARAS approaches for green supplier selection. Nallusamy, Sri Lakshmana Kumar, Balakannan, and Chakraborty (2016) used the fuzzy logic, AHP and artificial neural networks for supplier evaluation and selection. The other AHP-based hybrid approaches include the studies of Zhongwei and Jianzhong (2008b), Cheng, Lee, and Tang (2009) and Lee (2009a).

3.5. ANP–TOPSIS

Some studies have applied the integration of the ANP and TOPSIS methods. Önüt, Kara, and Işik (2009) developed a fuzzy supplier evaluation approach based on the analytic net-work process and the TOPSIS methods to help a telecommunication company in the global system for mobile communications (GSM) sector in Turkey. Shirinfar and Haleh (2011) proposed a hybrid approach based on fuzzy ANP, fuzzy TOPSIS, fuzzy PROMETHEE and fuzzy goal programming for the evaluation and selection of suppliers. Shemshadi, Toreihi, Shirazi, and Tarokh (2011) presented an MADM model for supplier risk evaluation by using the ANP and fuzzy TOPSIS methods. Jajimoggala, Kesava Rao, and Beela (2011) proposed a hybrid model, which incorporates the ANP and TOPSIS techniques to rank competing suppliers in terms of their overall performances. Büyüközkan and Çifçi (2012b) devel-oped a novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers. Wu, Hsieh, and Chang (2013) proposed an MADM model for supplier selection by using a combination of the fuzzy Delphi method, ANP, and TOPSIS, and applied it to a real case. Sinrat and Atthirawong (2014) presented a concep-tual framework by integration of fuzzy ANP and TOPSIS for supplier selection based on supply chain risk management. Kuo, Hsu, and Chen (2015) identified 13 criteria of carbon management under four dimensions and developed a framework for the supplier evaluating process for carbon management by integrating fuzzy ANP and fuzzy TOPSIS approaches. Govindaraju, Akbar, Gondodiwiryo, and Simatupang (2015) applied an integrated fuzzy ANP–TOPSIS approach for selecting strategic suppliers. Rouyendegh (2015) developed an integrated model for supplier selection based on the ANP and intuitionistic fuzzy TOPSIS.

3.6. ANP–LP

Integration of the ANP and linear programming is another hybrid approach that has been used by researchers. Lin (2009) proposed an integrated fuzzy ANP and multi-objective linear programming approach for supplier evaluation and order allocation. Lin (2012) integrated fuzzy ANP and fuzzy multi-objective linear programming for supplier evaluation and selec-tion. Palanisamy and Abdul Zubar (2013) developed a hybrid MADM approach by inte-grating fuzzy QFD, ANP and linear programming for evaluating and selecting appropriate

suppliers in automotive component manufacturing. Huang and Hu (2013) presented a two-stage solution approach for supplier selection using the fuzzy analytic network process, goal programming and De Novo programming (DNP). Bakeshlou, Khamseh, Asl, Sadeghi, and Abbaszadeh (2017) studied a fuzzy five-objective green supplier selection model using an integrated approach based on fuzzy ANP and fuzzy multi-objective linear programming.

3.7. Other ANP-based approaches

Some of studies have integrated the ANP approach with some other techniques for fuzzy supplier evaluation and selection. Tseng, Chiang, and Lan (2009) proposed a model for selection of optimal suppliers in a supply chain management strategy using the analytic network process and Choquet integral. Tuzkaya, Ozgen, Ozgen, and Tuzkaya (2009) developed an integrated fuzzy MADM approach based on fuzzy ANP and fuzzy PROMETHEE methods for environmental performance evaluation of suppliers. Büyüközkan and Çifçi (2011) presented a novel fuzzy multi-attribute decision framework for sustainable supplier selection with incomplete information based on fuzzy ANP and fuzzy preference relations. Bhattacharya et al. (2014) proposed an intra-organisational collaborative decision-making approach for green supply chain performance measurement of suppliers using the fuzzy analytic network process and a green-balanced scorecard. Lee, Kang, Lin, and Wu (2013) developed a hybrid model for supplier selection based on fuzzy ANP and DEMATEL approaches. Rezaei, Abedini Naeeni, and Sabet Motlagh (2013) presented an integrated approach based upon fuzzy ANP, fuzzy VIKOR and multi-objective mixed integer non-linear programming to determine the appropriate suppliers in a cable industry supply chain. Liou, Chuang, and Tzeng (2014) introduced a model for supplier evaluation and improvement using the fuzzy integral, ANP and DEMATEL approaches. Sinrat and Atthirawon (2015) proposed an integrated factor analysis and fuzzy analytic network process model for supplier selection based on supply chain risk.

3.8. TOPSIS–LP

The TOPSIS method has also been integrated with linear programming in the literature. Razmi, Songhori, and Khakbaz (2009) proposed a framework for supplier evaluation and order allocation based on fuzzy TOPSIS and multi-objective integer programming. Guneri, Yucel, and Ayyildiz (2009) developed an integrated fuzzy TOPSIS–LP approach for supplier selection and order allocation processes. Liao and Kao (2011) presented an integrated model based on fuzzy TOPSIS and multi-choice goal programming (MCGP) approaches to solve the supplier selection problem. Soner Kara (2011) proposed an integrated methodology for supplier selection problems using a two-stage stochastic programming model and the fuzzy TOPSIS method. Jolai, Yazdian, Shahanaghi, and Azari Khojasteh (2011) introduce a two-phase model by integrating fuzzy TOPSIS and multi-objective mixed integer linear programming for purchasing multiple products from multiple suppliers. Kilic (2013) integrated the fuzzy TOPSIS method with mixed integer linear programming for supplier selection in a multi-item multi-supplier environment. Singh (2014) presented a hybrid TOPSIS–LP approach for supplier evaluation and demand allocation problems. Rouyendegh (Babek Erdebilli) and Saputro (2014) developed a model for supplier evaluation based on fuzzy TOPSIS and multi-choice goal programming. Igoulalene, Benyoucef, and Tiwari

(2015) proposed two hybrid models based on a fuzzy consensus-based possibility measure, fuzzy TOPSIS, fuzzy consensus-based neat ordered weighted averaging (OWA) and goal programming for the strategic supplier selection problem.

3.9. Other TOPSIS-based approaches

The TOPSIS method could be combined with many approaches for supplier selection in fuzzy environment. Fan, Hong, and Liu (2008) integrated the rough set theory with the fuzzy TOPSIS method to deal with supplier selection problems. Büyüközkan and Ersoy (2009) proposed a hybrid approach to supplier evaluation based on fuzzy axiomatic design and fuzzy TOPSIS methods. Chen (2011) developed a structured methodology for supplier selection and evaluation using strengths–weaknesses–opportunities–threats (SWOT) analysis and the TOPSIS and DEA methods under fuzzy environments. Dalalah, Hayajneh, and Batieha (2011) introduced a fuzzy MADM approach based on a modified DEMATEL and fuzzy TOPSIS approach for supplier selection and applied it to a real case study. Govindan, Khodaverdi, and Jafarian (2013) proposed a fuzzy multi-attribute approach for measuring sustainability performance of suppliers based on triple bottom line and fuzzy TOPSIS approaches. Mukherjee and Kar (2013) developed a novel three-phase hybrid approach to supplier evaluation and selection based on fuzzy preference degree and TOPSIS methods. Arabzad, Ghorbani, Razmi, and Shirouyehzad (2015) integrated SWOT analysis with fuzzy TOPSIS and linear programming for supplier selection and order allocation problems. Arshadi Khamseh and Mahmoodi (2014) proposed a new hybrid fuzzy TOPSIS–TODIM method for green supplier selection using fuzzy time functions. Orji and Wei (2014) applied fuzzy logic, DEMATEL and TOPSIS to effectively analyse the interdependencies between sustainability criteria and to select the best sustainable supplier in a fuzzy environment. Kar, Chatterjee, and Kar (2014) integrated fuzzy extent analysis, fuzzy cognitive map, fuzzy decision map and fuzzy TOPSIS to select the appropriate supplier in a supply chain. Cao, Wu, and Liang (2015) proposed a hybrid MADM approach based on an intuitionistic fuzzy judgement matrix and TOPSIS method multi-criteria decisions for green supplier selection. Wood (2016) developed a multi-attribute decision-making technique using fuzzy and intuitionistic fuzzy TOPSIS with flexible entropy weighting to select the appropriate supplier for development of petroleum industry facilities. Lima-Junior and Carpinetti (2016) combined the SCOR (Supply Chain Operations Reference) model with fuzzy TOPSIS for supplier evaluation and management and applied it to an automobile supply chain.

3.10. VIKOR-based approaches

The VIKOR method is also one of the MADM methods that have been integrated with some other approaches for the process of fuzzy evaluation and selection of suppliers. Dai, Liu, and Zhang (2008) integrated the fuzzy AHP and fuzzy VIKOR methods for application to supplier selection problems. Mohammady and Amid (2011) proposed a hybrid approach based on fuzzy AHP and fuzzy VIKOR methods for supplier selection in an agile and modular virtual enterprise. Wu and Liu (2011) developed a supplier selection model based on fuzzy VIKOR and fuzzy TOPSIS methods. Kuo, Shia, Chen, and Ho (2011) presented an MADM framework for evaluating the green suppliers of the printed circuit board factories based on the fuzzy AHP and VIKOR methods. Mishra, Samantra, Datta, and Mahapatra

(2012) proposed a multi-attribute group decision-making approach for supplier evaluation by integration of fuzzy linguistic modelling and the fuzzy VIKOR method. Chaghooshi, Fathi, Faghih, and Zarchi (2012) presented an integrated model for supplier evaluation based on the DEMATEL, fuzzy ANP and VIKOR methods and applied it to a tyre manufacturing company. Jiang and Yao (2013) developed an integrated approach using fuzzy AHP and interval-valued intuitionistic fuzzy VIKOR methods for selection of a supplier of automobile parts. Ayazi, Moradi, and Paksoy (2014) presented a model for supplier selection and order allocation based on the fuzzy VIKOR method and fuzzy multi-objective programming approach. Akman (2015) proposed a hybrid approach for evaluation of suppliers using fuzzy c-means clustering and VIKOR methods. Awasthi and Kannan (2016) developed an integrated approach based on a fuzzy NGT (nominal group technique) and the VIKOR method for evaluating green supplier development programmes.

3.11. Other hybrid approaches

In addition to the abovementioned hybrid approaches, some researchers have integrated other approaches for evaluation of suppliers in fuzzy environments. Bevilacqua, Ciarapica, and Giacchetta (2006) proposed a hybrid approach based on fuzzy QFD and the fuzzy suitability index (FSI) for supplier selection. Lee (2006) integrated the fuzzy preference relation and linear programming to select suppliers. Amin and Razmi (2009) developed an integrated fuzzy approach based on the QFD for supplier management, and applied it to internet service provider selection. Shen and Yu (2009) presented a hybrid fuzzy approach considering the strategic and operational factors for enhancing the efficacy of supplier selection decision-making at the initial stage of new product development. Leng and Zhang (2010) used an integrated model based upon fuzzy set theory and grey-based rough set theory for supplier evaluation. Xiao, Chen, and Li (2012) integrated the fuzzy cognitive map (FCM) with a fuzzy soft set model for solving the supplier selection problem based on risk evaluation. Mirhedayatian, Azadi, and Farzipoor Saen (2014) proposed a novel network DEA model for evaluating green supply chain practices in the presence of dual-role factors, undesirable outputs and fuzzy data. Dursun and Karsak (2013) developed an integrated approach based on fuzzy QFD and the fuzzy weighted average (FWA) method for evaluation of suppliers. Sepehriar, Eslamipoor, and Nobari (2013) presented a hybrid approach for supplier selection and order allocation based on the fuzzy ELECTRE method and linear programming. Tseng and Chiu (2013) proposed a model for evaluating firms' green supply chain management based on the fuzzy set theory and grey relational analysis. Omurca (2013) developed a hybrid approach based on fuzzy c-means and rough set theory as a new solution for supplier selection, evaluation and development problems. Karsak and Dursun (2014) introduced a fuzzy integrated methodology using DEA, QFD and fuzzy weighted average for supplier evaluation in a private hospital in Istanbul. Dursun and Karsak (2014) proposed an integrated approach for supplier selection based on 2-tuple fuzzy representation and the QFD model. Tahriri, Mousavi, Hozhabri Haghighi, and Zawiah Md Dawal (2014) applied a hybrid fuzzy Delphi and fuzzy inference system to the supplier ranking and selection problem. Mehregan, Hashemi, Karimi, and Merikhi (2014) analysed the interactions between sustainability supplier selection criteria using ISM and fuzzy DEMATEL. Karsak and Dursun (2015) employed the OWA operator to develop an integrated methodology for supplier evaluation based on 2-tuple fuzzy sets and QFD. Mahmoudi, Sadi-Nezhad, and Makui (2015) proposed an

extended fuzzy PROMETHEE founded on a fuzzy rule-based system for supplier selection problems. Keskin (2015) used an integrated fuzzy DEMATEL and fuzzy c-means algorithm for supplier evaluation and selection. Fallahpour, Olugu, Musa, Khezrimotlagh, and Wong (2016) developed an integrated model for green supplier selection under fuzzy environments based on the data envelopment analysis and genetic programming approach.

4. Analysis of the reviewed papers

In this section, we analyse the reviewed papers with respect to some important aspects. First of all, the papers are analysed based on the frequency of MADM approaches used in them, and the most frequent approaches are identified. Then, the most influential journal articles are determined according to the number of citations of the reviewed journal papers. Number of publications in each year, journal and country of origin are also analysed in this section.

4.1. Most frequent approaches

We analysed the frequency of the MADM approaches within two categories: single approaches and hybrid approaches. Table 5 shows the frequency of single approaches according to the type of the paper (journal paper, book chapter or conference paper). As can be seen in this table, 26.77% of published papers in the single approaches category used the AHP method for supplier evaluation and selection. Therefore, the AHP method is the most frequent single approach (without considering the 'Other single approach' subcategory). The TOPSIS method is the second most popular single approach with 20.71% of papers. In the hybrid approaches category, the AHP–TOPSIS approach is the most frequent with 16.31% of studies. Also, 13.48% of the studies in this category used the integrated AHP–LP approach, and 14.18% applied the AHP method integrated with other methods. These facts show that the AHP method is also the most prevalent method in hybrid approaches. The ANP–TOPSIS, TOPSIS–LP and other TOPSIS-based approaches account for 22.69%

Table 5. Frequency of single and hybrid approaches in the reviewed papers.

	Approach	Journal paper	Book chapter	Conference paper	Total	% of single/ hybrid	% of total
Single	AHP	29	3	21	53	26.77	15.63
	ANP	7	0	5	12	6.06	3.54
	TOPSIS	28	1	12	41	20.71	12.09
	VIKOR	10	0	0	10	5.05	2.95
	MOORA	4	0	0	4	2.02	1.18
	ELECTRE	4	0	0	4	2.02	1.18
	DEMATEL	5	0	0	5	2.53	1.47
	DEA	4	1	3	8	4.04	2.36
	Other single approaches	47	1	13	61	30.81	17.99
Hybrid	AHP-TOPSIS	19	0	4	23	16.31	6.78
	AHP–LP	19	0	0	19	13.48	5.60
	AHP–DEA	3	2	0	5	3.55	1.47
	Other AHP-based	15	0	6	21	14.18	5.90
	ANP–TOPSIS	9	0	1	10	7.09	2.95
	ANP–LP	5	0	0	5	3.55	1.47
	Other ANP-based	7	0	1	8	5.67	2.36
	TOPSIS–LP	8	0	1	9	6.38	2.65
	Other TOPSIS-based	11	0	2	13	9.22	3.83
	VIKOR-based	8	0	2	10	7.09	2.95
	Other hybrid approaches	16	0	3	19	13.48	5.60

Source: Authors' calculations.

of papers in the hybrid approaches category. Thus, the TOPSIS method can be considered as the second most frequently used method in the hybrid approaches. Total percentages show that using the AHP method as a single approach constitutes a considerable number of papers on the evaluation and selection of suppliers in the fuzzy environment.

4.2. Most influential articles

In this analysis, we only consider the reviewed journal papers (without considering journal papers published in 2016), and book chapters and conference papers are excluded. For this purpose, the number of citations of the reviewed journal papers was extracted from Scopus to analyse their degree of influence in the literature. Where there are articles with the same publication date, the number of citations could be an appropriate measure to compare their influence in the literature. However, this is not rational if the dates of publications are different. For this reason, we use a measure that normalises the number of citations of a paper by its publication date. In other words, it gives an estimate of the average citations per year (ACPY) of a paper. This measure is defined as follows:

$$\text{ACPY} = \frac{\text{Total number of citations of the paper}}{\text{Current year - Year of publication of the paper}}$$

In the above formula, the value of the current year is 2016. Using the ACPY formula and the number of citations of the reviewed journal papers, the top 50 influential articles were determined. The results, which are sorted according to ACPY values, are represented in Table 6. The author(s), year of publication, journal, subcategory, number of citations and ACPY measure of the papers are included in this table.

According to this table, the first influential paper applied the TOPSIS method as a single approach, was published in the *International Journal of Production Economics* and cited 626 times in the literature. The second paper used the AHP method as a single approach, was published in *Omega* and cited 486 times. The third paper also used the TOPSIS method as a single approach, was published in *Expert Systems with Applications* and cited 354 times. Moreover, *Expert Systems with Applications* accounts for 48% (24 papers) in this list, which shows the high level of influence of this journal in the field of the evaluation and selection of suppliers within fuzzy environments.

4.3. Year of publications

Table 7 presents the number of journal papers, book chapters and conference papers in different years (over the period 2001 to 2016), and Figure 2 shows the graphical representation of the data. As can be seen, although there have been some fluctuations in the total number of papers in some years, the overall trend shows the increase in the number of studies on application of multi-attribute decision-making approaches in the evaluation and selection of suppliers within the context of fuzzy sets. As previously stated, the AHP and TOPSIS methods are the most frequent approaches in both single and hybrid approaches. In Figure 3, we depict the number of papers which applied these methods in their studies (as a single or hybrid approach) according to the year of publication. It can be seen that the overall patterns of using these methods in different years are similar, and the variations are relatively consistent with the variations in the total number of papers. Also, the linear trend lines related to the AHP and TOPSIS methods show an increasing trend in using these methods.

Table 6. Top 50 influential papers and the corresponding information.

| No.	Author(s) and year	Journal	Subcategory	Citations	ACPY
1	Chen et al. (2006)	International Journal of Production Economics	TOPSIS	626	62.60
2	Chan and Kumar (2007)	Omega	AHP	486	54.00
3	Boran et al. (2009)	Expert Systems with Applications	TOPSIS	354	50.57
4	Gülçin Büyüközkan and Çifçi (2012b)	Expert Systems with Applications	ANP–TOPSIS	161	40.25
5	Kannan et al. (2014)	European Journal of Operational Research	TOPSIS	59	29.50
6	Sanayei et al. (2010)	Expert Systems with Applications	VIKOR	176	29.33
7	Wang et al. (2009)	Applied Soft Computing	AHP–TOPSIS	187	26.71
8	Lee et al. (2009)	Expert Systems with Applications	AHP	181	25.86
9	Govindan et al. (2013)	Journal of Cleaner Production	Other TOPSIS-based approaches	77	25.67
10	Krishnendu Shaw et al. (2012)	Expert Systems with Applications	AHP–LP	101	25.25
11	Chan et al. (2008)	International Journal of Production Research	AHP	201	25.13
12	Deng and Chan (2011)	Expert Systems with Applications	TOPSIS	117	23.40
13	Reza Rostamzadeh et al. (2015)	Ecological Indicators	VIKOR	23	23.00
14	Awasthi et al. (2010)	International Journal of Production Economics	TOPSIS	134	22.33
15	Lin (2013)	Journal of Cleaner Production	DEMATEL	67	22.33
16	Kannan et al. (2013)	Journal of Cleaner Production	AHP–LP	66	22.00
17	Lee (2009b)	Expert Systems with Applications	AHP	153	21.86
18	Lima Junior et al. (2014)	Applied Soft Computing	AHP–TOPSIS	42	21.00
19	Önüt et al. (2009)	Expert Systems with Applications	ANP–TOPSIS	144	20.57
20	Tseng and Chiu (2013)	Journal of Cleaner Production	Other hybrid approaches	61	20.33
21	Shemshadi et al. (2011)	Expert Systems with Applications	VIKOR	100	20.00
22	Kilincci and Onal (2011)	Expert Systems with Applications	AHP	98	19.60
23	Chang et al. (2011)	Expert Systems with Applications	DEMATEL	94	18.80
24	Vinodh et al. (2011)	Expert Systems with Applications	ANP	91	18.20
25	Gülçin Büyüközkan and Çifçi (2011)	Computers in Industry	Other ANP-based approaches	89	17.80
26	Bevilacqua et al. (2006)	Journal of Purchasing & Supply Management	Other hybrid approaches	175	17.50
27	Chou and Chang (2008)	Expert Systems with Applications	Other single approaches	137	17.13
28	Chamodrakas et al. (2010)	Expert Systems with Applications	AHP–LP	101	16.83
29	Liao and Kao (2011)	Expert Systems with Applications	TOPSIS–LP	84	16.80
30	Atefeh Amindoust et al. (2012)	Applied Soft Computing	Other single approaches	66	16.50
31	Mirhedayatian et al. (2014)	International Journal of Production Economics	Other hybrid approaches	33	16.50
32	Zeydan et al. (2011)	Expert Systems with Applications	AHP–TOPSIS	80	16.00
33	Chen (2011)	Information Sciences	Other TOPSIS-based approaches	79	15.80
34	Zouggari and Benyoucef (2012)	Engineering Applications of Artificial Intelligence	AHP–TOPSIS	61	15.25
35	Tseng et al. (2009)	Computers & Industrial Engineering	Other ANP-based approaches	106	15.14
36	Lu et al. (2007)	International Journal of Production Research	AHP	135	15.00
37	Rezaei and Ortt (2013)	European Journal of Operational Research	AHP	44	14.67
38	Arpan Kumar Kar (2014)	Expert Systems with Applications	AHP–LP	28	14.00

|				
39	Chen et al. (2011)	Expert Systems with Applications	Other single approaches	67	13.40
40	Tuzkaya et al. (2009)	International Journal of Environmental Science & Technology	Other ANP-based approaches	88	12.57
41	Rezaei et al. (2014)	Expert Systems with Applications	Other AHP-based approaches	24	12.00
42	Dalalah et al. (2011)	Expert Systems with Applications	Other TOPSIS-based approaches	59	11.80
43	You et al. (2015)	Expert Systems with Applications	VIKOR	11	11.00
44	Noorul Haq and Kannan (2005)	The International Journal of Advanced Manufacturing Technology	AHP	106	10.60
45	Lin (2009)	Applied Mathematical Modelling	ANP–LP	74	10.57
46	Amin and Razmi (2009)	Expert Systems with Applications	Other hybrid approaches	71	10.14
47	Arpan Kumar Kar (2015)	Journal of Computational Science	Other AHP-based approaches	10	10.00
48	Wang and Yang (2009)	Expert Systems with Applications	AHP–LP	68	9.71
49	Aydin Keskin et al. (2010)	Expert Systems with Applications	Other single approaches	58	9.67
50	Dursun and Karsak (2013)	Applied Mathematical Modelling	Other hybrid approaches	27	9.00

Source: Authors' calculations.

Table 7. Distribution of publications by year.

Year	Journal papers	Book chapters	Conference papers	Total
Before 2005	5	0	0	5
2006	3	0	3	6
2007	4	0	3	7
2008	8	0	12	20
2009	23	0	7	30
2010	15	1	7	23
2011	36	0	8	44
2012	30	0	9	39
2013	38	0	8	46
2014	34	4	11	49
2015	43	3	5	51
2016 (Up to May)	19	0	0	19

Source: Authors' calculations.
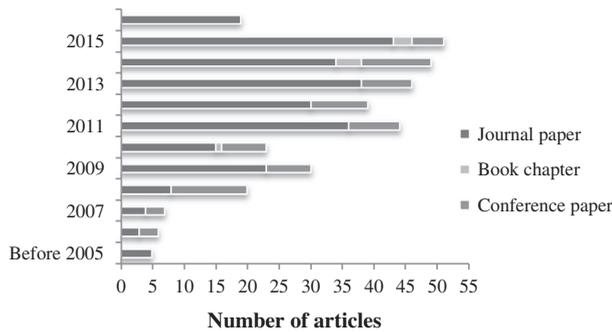
Figure 2. Graphical distribution of publications by year. Source: Authors' graph.
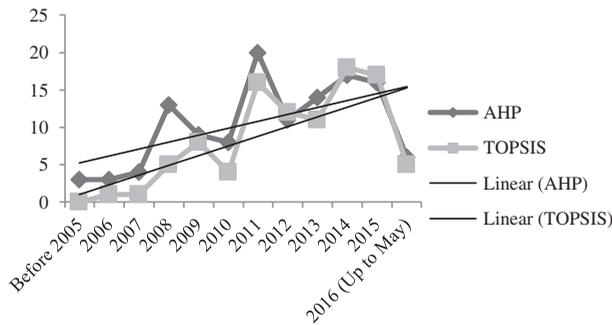
Figure 3. Trend of publications using the AHP and TOPSIS methods. Source: Authors' graph.

4.4. National analysis of studies

We also analysed the distribution of the reviewed papers according to the country of origin. Table 8 presents countries with more than two papers in the field of fuzzy evaluation and selection of suppliers. Also, this table includes the period of the publications and the total number of citations of the journal papers from each country. As can be seen, more than 70% of publications (248 publications) are from five countries (China, Iran, Turkey, Taiwan and India), and China with 67 publications is the leading country in terms of number of

publications followed by Iran with 50 publications. On the other hand, Taiwan with 2314 citations has the first place with respect to the citations of its journal papers, followed by Turkey with 1657 citations and Hong Kong with 724 citations.

4.5. Analysis of publishing journals

The reviewed papers were also analysed based on the journals which published them. Figure 4 shows the journals with more than two publications (0.5% of publications) on the

Table 8. Distribution of publications by country.

Country	Number of publications	Citations	Years
China	67	433	2006–2016
Iran	50	563	2008–2016
Turkey	47	1657	2003–2016
Taiwan	43	2314	2006–2016
India	41	484	2006–2016
Malaysia	14	86	2011–2015
Canada	8	205	2007–2016
USA	8	254	2001–2015
Denmark	6	235	2013–2016
Italy	6	256	2002–2012
Brazil	5	76	2012–2016
Hong Kong	5	724	2007–2015
UK	5	100	2008–2016
Serbia	4	1	2011–2015
Australia	3	1	2011–2016

Source: Authors' calculations.
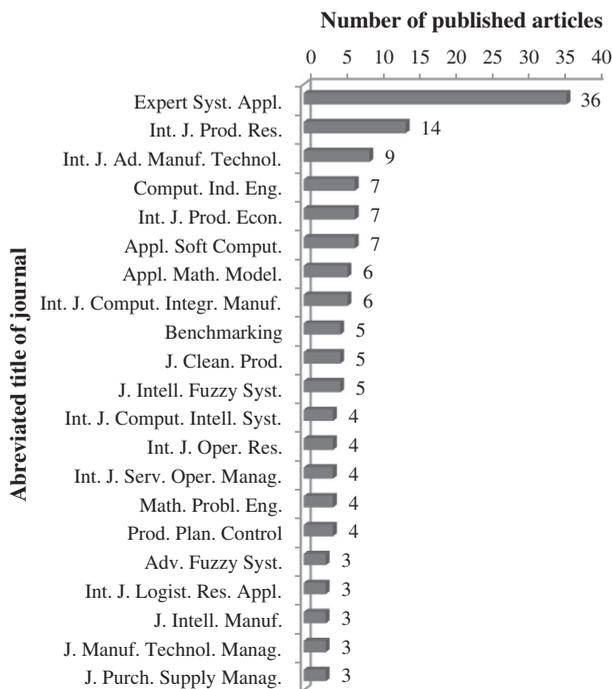
Figure 4. Graphical distribution of publications by journal. Source: Authors' graph.

evaluation and selection of suppliers using MADM approaches within fuzzy environments. The titles of the journals are abbreviated in this figure. With respect to this analysis, *Expert Systems with Applications* is the leading journal in this field with 36 published papers (10.62% of publications). Moreover, the *International Journal of Production Research* is in the second place with 14 publications (4.13%), followed by *The International Journal of Advanced Manufacturing Technology* with nine publications (2.65%). As can be seen in Figure 4, the top six journals have published almost 24% of all papers which applied MADM approaches in fuzzy supplier evaluation and selection. Moreover, the top 16 journals account for almost 38% of all publications.

5. Findings and discussion

Regarding supply chain management practices, the process of supplier evaluation and selection has been identified as an important problem which could affect the efficiency of a supply chain. This process could be considered as a multi-criteria decision-making problem. Hence, many MADM and multi-objective decision-making (MODM) approaches have been applied to this problem up to now. Because the information in the evaluation process is usually uncertain, the fuzzy approaches have been widely utilised for decision-making problems. Many studies can be found that applied the fuzzy MADM approaches to various fields of science and engineering (Celik, Gul, Aydin, Gumus, & Guneri, 2015; Kahraman, Onar, & Oztaysi, 2015; Mardani, Jusoh, & Zavadskas, 2015). One of the fields that the fuzzy MADM approaches have been applied to is the evaluation and selection of suppliers. Although some studies have considered a review of applications of MADM approaches in this field, no study has focused on this problem in a fuzzy environment. Accordingly, this study considers the fuzzy supplier evaluation and selection problem for the first time in the literature. For this purpose, the reviewed papers were classified in terms of different approaches in two categories: single approaches and hybrid approaches. In the single approaches category, the AHP and TOPSIS methods, and in the hybrid approaches category, AHP–TOPSIS were the most frequently used approaches. These facts show the importance of the AHP and TOPSIS methods in this field of research. According to analysis of the year of publication, the total number of papers in this field has an increasing trend. This increasing trend is also reflected in the number of papers used the AHP and TOPSIS methods or both of them. The popularity of the AHP method could be because of the hierarchical structure of the supplier evaluation and selection problems which could be handled by this method. On the other hand, the simplicity and robustness of the TOPSIS method for decision-making are probably the main reasons for using this method in many studies in the literature. The most cited articles also confirmed that these two methods have been very useful in other studies.

6. Conclusion

Because of consequential role of supplier evaluation and selection in the efficiency of a supply chain, this problem has been widely studied by researchers in past years. The MADM approaches have been the most commonly used to deal with this problem. Due to the uncertainty of information in the process of decision-making, the supplier evaluation and selection problem could be considered in the context of fuzzy sets. This paper has presented a review of the publications using the MADM approaches for the problem of evaluation

and selection of suppliers in fuzzy environments. We reviewed a total of 339 publications in this field and classified them in two categories according the applied MADM approaches. The first category includes single approaches which consist of subcategories such as AHP, ANP, TOPSIS, VIKOR. Hybrid approaches such as AHP-TOPSIS, AHP-LP, TOPSIS-LP are included in the second category. The analyses showed that the AHP and TOPSIS methods are the prevalent approaches in both single and hybrid approaches. Moreover AHP-TOPSIS is the most popular integrated approach applied by researchers. There is an increasing trend in the total number of publications in this field which can also be seen in the trend-line of the AHP and TOPSIS methods. The results of the national analysis show that China accounts for most of the papers; however Taiwan has the highest number of citations. Also, in analysis of publishing journals, *Expert Systems with Applications*, *International Journal of Production Research* and *The International Journal of Advanced Manufacturing Technology* were identified as the leading journals in this field.

Disclosure statement

No potential conflict of interest was reported by the authors.

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