MULTI-CRITERIA DECISION-MAKING METHODS FOR SUPPLIER SELECTION: A LITERATURE REVIEW

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ABSTRACT

A firm's multi-criteria decision-making (MCDM) process is important because of its need to select and work with various suppliers. The process identifies the problems associated with selecting the supplier, , determining convenient criteria, expressing interactions clearly, and usage. These are all suitable methods for finding a solution to these MCDM problems.

Considering more than one criterion (and even the sub-criteria of these criteria) during supplier selection makes the selection uncertain. Conventional methods cannot generate a realistic solution to the problem. Using MCDM methods considerably simplifies solving the problem, and enables decision-makers to make better decisions. In this study, a literature review was performed on MCDM methods used between 2001 and 2014 for the supplier selection problem. MCDM methods used in supplier selection are categorised into three main methods, and a summary table of the reviewed studies is presented.

OPSOMMING

'n Firma se multi-maatstaf besluitnemingsproses is belangrik as gevolg van die behoefte om verskeie verskaffers te kies en dan mee saam te werk. Die proses identifiseer die probleme geassosieer met die kies van die verskaffer, die bepaling van gerieflike kriteria, en wat die duidelike uitdruk van interaksies en die gebruik daarvan, insluit. Hierdie is almal gepaste metodes vir die vind van 'n oplossing tot hierdie multi-maatstaf besluitnemingsproses probleme.

Die oorweging van meer as een maatstaf (en selfs die sub-maatstawwe van hierdie maatstaf) tydens verskaffer seleksie maak die seleksie onseker. Tradisionele metodes kan nie 'n realistiese oplossing tot die probleem genereer nie. Deur van multi-maatstaf besluitnemingsprosesmetodes gerbuik te maak word die oplos van die probleem aansienlik vereenvoudig en dit stel besluitnemers in staat om die beter besluite te neem. 'n Literatuurstudie is gedoen op multi-maatstaf besluitnemingsprosesmetodes gebruik vir die verskaffer seleksie probleem van 2001 tot 2014. Die metodes word in drie afdelings verdeel en 'n opsommende tabel van die studies word voorgehou.

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1 INTRODUCTION

Partners of a supply chain are the critical determinants of supply chain behaviour. In this chain, the selection of the partner or the sustainability of partnership is very important for constituting and continuing the supply chain [1].

In today's competitive environment, the decision about supplier selection is very important to the success of production management [2]. Where firms experience intensive competition, working with reliable suppliers is crucial. For that reason, firms seek to work with suppliers who can render service at the required quality level, are suitable in terms of cost, and are flexible about changes in demand. Due to the variety and abundance of expectations of sister companies that work with the suppliers, the problems related to the selection of suppliers are among the complexities frequently encountered by enterprises. Supplier selection is among the most familiar multi-criteria decision-making (MCDM) problems [3]. MCDM methods have a very broad area of use for arranging a series of available alternatives, in terms of multiple criteria. MCDM is a process aimed at finding the best alternative among all of the suitable alternatives. In almost all of the problems, the abundance of criteria for the comparison of alternatives has become widespread. In other words, decision-makers seek to solve the many problems raised by MCDM [4].

Multi-objective decision-making methods are analytical methods. These enable the simultaneous assessment of many measurable and non-measurable strategic and operational factors, and also include many people in the decision-making process. The use of these methods in the decision-making process supports managers with assessing various alternatives, thus enabling a more effective use of their enterprise's resources [5].

In this study, 91 studies that were performed between 2001 and 2014 on the multi-criteria supplier selection were reviewed in order to determine the criteria used for the selection of suppliers and methods. Sector-based distribution of the reviewed papers is presented in Figure 1.

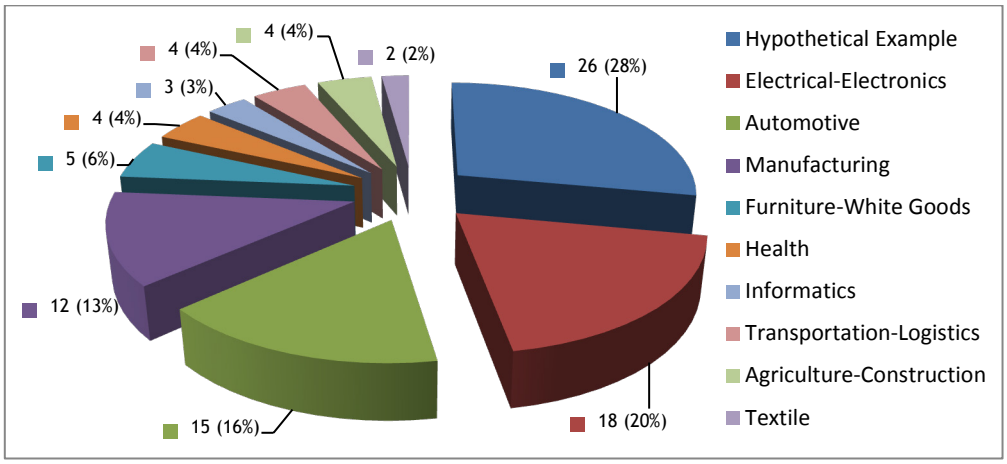

Figure 1: Sector-based distribution of the reviewed papers (see online for colour version)

From Figure 1, it can be noted that 28 per cent of the supplier selection studies presented in the reviewed literature involved hypothetical examples, 20 per cent were from the electrical-electronics sector, 16 per cent from the automotive sector, and 13 per cent from the manufacturing sector. Thus it was determined that supplier selection studies of multi-criteria supplier selection were most often done in the electrical-electronics and automotive sectors. Since the products of these two sectors generally consisted of many components, the selection of the suppliers with whom they should have been in cooperation to provide these components was very important for the producers in these sectors.

The methods that were used in the reviewed papers are summarised under the following three main sections: individual, hybrid, and hybrid fuzzy methods.

2 INDIVIDUAL METHODS

In this section, a detailed literature review is presented on individual MCDM methods that were used from 2001 to 2014 for the supplier selection problem. The reviewed papers are categorised into groups on the basis of the individual methods that were used for the different studies presented in the papers. These individual methods are outlined in the following 12 subsections.

2.1 Analytical hierarchy process (AHP)

Muralidharan et al. [6] considered group decisions during supplier selection. Suppliers were assessed individually in the group through the AHP method, and the results obtained determined the confidence intervals of each supplier. Suppliers were assessed by ten decision-makers on the basis of their quality, technical activities, and delivery criteria. Muralidharan et al. argued that suppliers should be assessed periodically in case long-term relations are established with the suppliers and they become unmotivated as a result. Therefore, the performances of suppliers were re-assessed and then compared with previous performances at the end of certain periods. Chan [7] used AHP and an interactive selection model to ease the decision-making procedures during supplier selection. In Chan's study, AHP was only used to generate the total scores of alternative suppliers; these would depend on the rates of relative significance. Chan and Chan [8] used AHP for supplier selection, using criteria that consisted of six basic assessment criteria and 26 other criteria whose relative significance was calculated according to the rates of the customer needs. Liu and Hai [9] used the AHP method for supplier selection in the furniture white goods sector. Depending on the criteria and sub-criteria selected by sixty managers, weights and scores were calculated for the suppliers. Hou and Su [10] used the AHP method for web-based supplier selection in the electrical-electronics sector. In this study, five alternative suppliers were arranged according to their priority weights. Chan et al.'s [11] study, which also used the AHP method for solving the supplier selection problem, included 14 criteria for supplier selection. With the help of a sensitivity analysis that was conducted at the end of the study, Chan et al. changed the relative significance rates of each criterion and examined the answers of the alternatives. Asamoah et al. [12] applied the AHP method for supplier evaluation and selection in a pharmaceutical manufacturing firm in Ghana. Bruno et al. [13] used the AHP method to select the best supplier in the Italian railway industry.

2.2 Analytical network process (ANP)

Depending on organisational factors and strategic performance measures, Sarkis and Talluri [14] used the ANP method for the assessment and selection of the best supplier. Bayazit [15] used the method to select the best supplier in a hypothetical example. Gencer and Gurpinar [16] also used the method in their study of supplier selection in the electrical-electronics sector. In their study, three alternative suppliers were assessed according to 45 sub-criteria under three main criteria, and the best supplier was selected at the end of the study. Liao et al. [17] used the method to select the optimal programme supplier for Taiwanese TV channels. Some of the selection criteria that were used in their application included performance (quality, launch at correct timing), feedback (reputation, rate, finance), interaction (relation, behaviour, communication), and production (creativity, price, time). At the end of their study, four suppliers were arranged according to their total weights.

2.3 Data envelopment analysis (DEA)

Narasimhan et al. [18] used the DEA method to assess alternative suppliers for an international company in the electrical-electronic sector. Mahdiloo et al. [19] also used DEA in their study of supplier selection in order to classify suppliers according to their efficiency scores. Dobos and Vörösmarty [20] developed a supplier selection method based on DEA.

2.4 Grey Relational Analysis (GRA)

Li et al. [21] used the GRA method for supplier selection. Four decision-makers assessed the supplier selection criteria, which included product quality, service, distribution, and price. Li et al. then analysed seven suppliers and chose the best supplier by considering relevant factors.

2.5 Artificial neural networks (ANN)

Florez-Lopez [22] used the ANN-based self-organising feature map (SOFM) approach in order to measure both the qualitative and the quantitative variables in supplier selection in a hypothetical example. At the end of the study, which assessed five suppliers, suppliers were divided into various sections on a map. In their study, Aksoy and Ozturk [23] performed the ANN-based supplier selection and assessment on data obtained from an automotive company; at the end of the study, suppliers were divided into three classes. Golmohammadi [24] applied the method to select the best supplier among 31 suppliers for eight products of a firm in the automotive sector. First a neural network model was designed in an attempt to assess the performance of the supplier according to the managers' decisions. Second, the model was re-assessed through the inputs and outputs of the model. Supplier scores were then obtained at the end of the application and a sensitivity analysis was conducted in the final phase of the study.

2.6 Goal programming (GP)

Karpak et al. [25] used the goal programming model for supplier selection and assessment; the amount of optimal product order was also determined at the end of their study. Jadidi et al. [26] used a multi-objective optimisation problem (MOOP) for solving supplier selection.

2.7 Linear programming (LP)

In their study, Ghodsypour and O'Brien [27] used the mixed-integer non-linear programming (MINLP) model for supplier selection. Talluri [28] used the binary-integer LP method for supplier selection in the health sector. Four models were developed to provide flexibility in supplier selection and to assist the customer in different types of sales. In their study, Talluri and Narasimhan [29] used the max-min approach for supplier selection in the health sector. Six alternative suppliers were assessed according to price, quality, and delivery criteria; the order level of suppliers was also calculated at the end of the study. Hong et al. [30] applied the mixed-integer LP method to supplier selection in the agricultural sector; the number of optimal suppliers and the optimal level of orders were also determined at the end of the study. Ng [31] used the weighted LP model to maximise the supplier score in the supplier selection problem. Ware et al. [32] developed MINLP to solve the dynamic supplier selection problem.

2.8 Multi-objective programming (MOP)

Narasimhan et al. [33] developed an MOP model to indicate the best supplier and the optimal order quantity. They suggested five criteria for supplier selection and derived the relative significance weights of the criteria before the solution of the optimality model. At the end of their study, Narasimhan et al. suggested that AHP could be used for generating the criteria weights. Ozkok and Tiryaki [34] applied the multi-objective linear supplier selection problem with multiple-item (MLSSP-MI) method to supplier selection and assessment for a textile firm in Turkey. Amin and Zhang [35] presented a multi-objective mixed-integer LP model for supplier selection, order allocation, and closed loop network configuration.

2.9 Simple multi-attribute rating technique (SMART)

Barla [36] used a SMART-based, five-stage methodology for supplier selection and assessment in a glass-producing firm,based on seven assessment criteria that they identified. At the end of the study, the supplier with the highest score was selected.

2.10 Case-based reasoning (CBR)

Choy et al. [37] applied the CBR method to information-based supplier selection and assessment in the production sector. At the end of their study, they arranged the alternative suppliers according to supplier selection performance.

2.11 Genetic algorithm (GA)

Liao and Rittscher [38] used the GA method for the supplier selection problem under stochastic demand quantities and lead time. They solved the supplier selection problem in five situations by comparing the selection criteria in two parts.

2.12 Technique for order preference by similarity to ideal solutions (TOPSIS)

Safa et al. [39] used TOPSIS to select the most suitable supplier according to criteria such as price, lead time, performance, and early payment.

From this review of the literature, the proportions of individual methods used for the supplier selection process are presented in Figure 2.

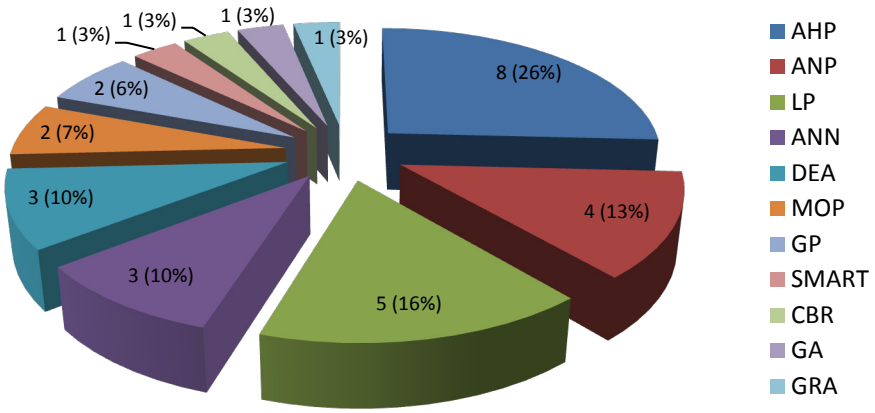

Figure 2: The individual methods used for supplier selection (see online for colour version)

Examining the results of the figure, it is noted that 26 per cent (8) of the individual methods consisted of AHP and 16 per cent (5) consisted of LP.

It was seen from the above results that AHP is frequently used in the individual methods. AHP seems to be a popular approach that attempts to quantify human judgement and opinion that other approaches may not take into account. Moreover, it is an effective statistical method that integrates with different approaches when working out the final choice of suppliers. The method is flexible and easy to understand, and can help decision-makers to handle risk management problems logically and rationally. The strongest features of AHP are that it gives numerical priorities from the subjective knowledge expressed in the estimates of paired comparison matrices. AHP's strong point lies in its ability to analyse a complex, multi-person, and multi-attribute problem hierarchically, and then to investigate each level of the hierarchy separately, combining the results as the analysis progresses.

3 HYBRID METHODS

In this section, a detailed literature review is presented on hybrid MCDM methods that were used from 2001 to 2014 for the supplier selection problem. The reviewed papers are categorised into groups on the basis of the hybrid methods that were used for the different studies presented in the papers. These methods, which are presented in the following three subsections, can be grouped as follows:

3.1 Hybrid AHP

The hybrid AHP-GP approach was used for supplier selection by Percin [40] and Kull and Talluri [41] in the automotive sector, and by Mendoza et al. [42] for a hypothetical example. AHP was used to calculate the assessment criteria, and suppliers were selected by transferring these weights into the GP model. Yang and Chen [43] applied the AHP method to calculate the relative significance weights of qualitative criteria in supplier selection; the supplier with the highest value was then selected as the best supplier by using the weights obtained from the AHP as the coefficients of the GRA model. Ramanathan [44] used DEA to assess suppliers' performance by using the total cost of the ownership and qualitative and quantitative information obtained from the AHP. In that study, the weights that were calculated in AHP were used as the DEA inputs. Sevkli et al. [45] used the AHP-DEA approach for supplier selection and assessment. In their study, while AHP was applied to calculate the relative weights of each supplier, DEA was applied to calculate the relative efficiency of each supplier. In their hypothetical supplier selection example, Xia and Wu [46] used the AHP and multi-objective mixed-integer programming (MIP) methods. Huang and Keskar [47] used the AHP-multi-attribute utility theory (MAUT) methods for supplier selection. In their study, while AHP was used to obtain the criteria weights, MAUT was used to establish the useful functions. At the end of that study, useful values were obtained for each supplier.

Ha and Krishnan [48] used a hybrid approach that consisted of AHP, ANN, and DEA for supplier selection in a firm producing auto components, according to assessment criteria. Kokangul and Susuz [49] used the AHP and non-linear integer programming methods in their study of supplier selection in a large automobile producer. The AHP method was used as an attempt to calculate the weights of suppliers in order to select them. The weights obtained from the AHP method were applied as the coefficients of the objective function in the suggested model, and the order amounts to be received from the suppliers were calculated accordingly. Chamodrakas et al. [50] used the AHP-based fuzzy preference programming (FPP) method to determine the best supplier. In their numerical study, Amid et al. [51] used the AHP-max–min fuzzy programming methods for supplier selection. The AHP method was applied to calculate the criteria weights and select the suppliers; the order quantity to be received from the suppliers was calculated by using the data obtained from the AHP in the max–min fuzzy programming method.

Mafakheri et al. [52] suggested a two-phase multiple-criteria dynamic programming approach to supplier selection and order allocation activities, which are very critical in supply chain management. While the AHP method was used to determine the orders of suppliers in the first phase, it was used to minimise the supplier order level and the costs of total supply chain, and to maximise the functions that are useful for the firm in the second phase of the order allocation model. Chen and Chao [53] applied the AHP model with the consistent fuzzy preference relations (CFPR) method to supplier selection in an electronic company in southern Taiwan. Rajesh and Malliga [54] developed an integrated approach that combined AHP and quality function deployment (QFD) to select suppliers strategically. Chen and Wu [55] applied a modified failure mode and effects analysis (MFMEA) method to select new suppliers from the perspective of supply chain risk, and the AHP method to determine the weight of each criterion and sub-criterion for supplier selection.

3.2 Hybrid ANP

Shyur and Shih [56] used a hybrid model for supplier selection in a study that combined the ANP and TOPSIS methods. During the first phase of the model, the required criteria were predetermined for supplier selection and the nominal group technique (NGT) was used to describe the internal dependency between the criteria. The ANP method was applied through the assessment of the criteria predetermined by three decision-makers, and alternative suppliers were arranged by using the criteria weights that were obtained at the end of the TOPSIS method. Finally, the supplier with the highest-ranking order in the closeness coefficient was determined as the best supplier. In a study of supplier selection in a firm that produces notebooks in Taiwan, Wu et al. [57] used the ANP and MIP methods. Criteria weights were calculated as a result of the assessments performed with the ANP

method, in light of the selection criteria that were predetermined during the first phase of the study. Suppliers were selected by using the weights obtained from the ANP in the MIP method during the second phase. Finally, the order levels to be received from the suppliers were also calculated.

3.3 Hybrid ANN

Kuo et al. [58] used a hybrid method that consisted of ANN, ANP, and DEA methods for the selection problem of environmentally-friendly suppliers in an electronic firm in Taiwan. In their study, the results obtained through the use of these three methods and dual uses of these methods were compared.

From this review of the literature, the hybrid methods used in supplier selection are summarised in Figure 3.

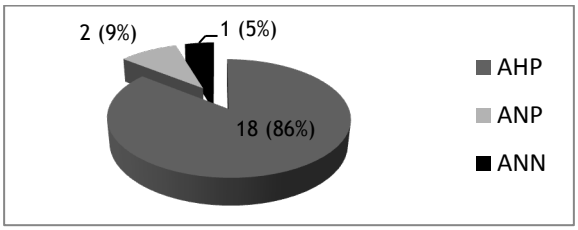

Figure 3: Hybrid methods used for supplier selection

From Figure 3, it is noted that a great majority (86 per cent (18)) of hybrid methods used in supplier selection consisted of AHP.

It can be concluded that AHP is easy to use, has great flexibility and wide applicability, and is logically consistent. It provides an estimate of additive utility weight that best matches the initial information provided by the decision-maker, and it provides a meaningful way to measure and combine tangible and intangible criteria in any decision. It can also be used with other techniques, such as mathematical programming, to take into account not only qualitative and quantitative factors, but also some real-world resource limitations (e.g., processing capacity, quality, and budget) [49]. AHP also has great capacity for handling qualitative and quantitative criteria used in such problems [50].

4 HYBRID FUZZY METHODS

In this section, a detailed literature review is presented of hybrid fuzzy methods that were used from 2011 to 2014 for the supplier selection problem. The reviewed papers are categorised into groups on the basis of the hybrid fuzzy methods that were used for the different studies presented in the papers. These methods, which are outlined in the following nine subsections, can be grouped as follows:

4.1 Fuzzy TOPSIS

Chen et al. [59] applied the fuzzy TOPSIS method to supplier selection in an advanced technology production firm. Depending on the five predetermined criteria for suppliers, three decision-makers assessed five alternative suppliers. At the end of the study, alternative suppliers were arranged according to their closeness coefficients. Shahanaghi and Yazdian [60] applied the fuzzy TOPSIS method to select the best supplier according to the predetermined criteria, in terms of the purchase of main components from alternative suppliers in an automotive company; the best supplier was selected at the end of the calculations that were performed after the assessment of four alternative suppliers by three decision-makers, according to the predetermined criteria. Buyukozkan and Ersoy [61] used the fuzzy TOPSIS method to select the external source suppliers of a firm operating in the informatics sector in Turkey. Boran et al. [62] used the TOPSIS method combined with the intuitionistic fuzzy set to select the supplier for a key component in the production process of an automotive company. An intuitionistic fuzzy weighted averaging (IFWA)

operator was used to aggregate the individual opinions of decision-makers in rating the importance of criteria and alternatives. At the end of the study, alternative suppliers were arranged according to their closeness coefficients.

In the study of Wang et al. [63], three suppliers were assessed and arranged by three decision-makers according to four supplier selection criteria, performed according to the fuzzy TOPSIS-based hierarchical TOPSIS method. At the end of the study, it was indicated that this method was more reasonable than other methods, and could be applied to the calculation of weights in future studies or other decision-making areas. Awasthi et al. [64] used the fuzzy TOPSIS method for supplier selection; 12 selection criteria, which were determined in line with expert opinion, were assessed by three expert decision-makers for four alternative suppliers, and then suppliers were arranged according to their closeness index. A sensitivity analysis was conducted at the end of the study. Chen [65] used a two-phase method that consisted of DEA and fuzzy TOPSIS methods for supplier selection in the textile sector in Taiwan. Liao and Kao [66] used the fuzzy TOPSIS and GP methods to select material suppliers for the purchase of key components in a firm producing clocks. In their study, a three-member decision-making committee assessed five alternative suppliers who were selected according to the predetermined criteria of supplier selection. In that study, fuzzy TOPSIS and GP were used in combination, and suppliers were arranged according to their closeness index. At the end of the study, the number of products to be received from suppliers was also determined. In a study performed in an automotive production factory that sought to purchase inside and outside mirrors for three automobile models, Jolai et al. [67] used fuzzy TOPSIS and GP methods to select the best supplier and determine the order quantity. Six suppliers chosen by the factory were then assessed by three decision-makers. The best supplier was selected with the fuzzy TOPSIS method and order quantity was determined by using the weights obtained from the fuzzy TOPSIS method combined with the GP method. At the end of the study, a sensitivity analysis determined that the results were consistent. Rouyendegh et al. [68] used a two-phase solution fuzzy TOPSIS method and multi-choice goal programming (MCGP) to select the best supplier. Junior et al. [69] used fuzzy TOPSIS and fuzzy AHP methods to aid the supplier selection decision process in the automotive industry.

4.2 Fuzzy AHP

In a study performed in the manufacturing sector, Chan and Kumar [70] used the fuzzy extended AHP method to select the best global supplier for supplying critical components used in the assembling process. Three suppliers, who had been chosen according to the predetermined selection criteria, were assessed in accordance with the whole main/sub-criteria; at the end of the study, the best global supplier was selected. Bottani and Rizzi [71] used fuzzy AHP and clustering analysis to select suppliers who enable the production of manufacturing and packaging machines of beverage products in Italy. In their study, while fuzzy AHP was applied to assess and arrange AHP alternatives, clustering analysis was applied to classify the arranged alternatives into convenient clusters; these applications reduced the number of suppliers from 92 to 18. Lee [72] suggested an analytical approach to select suppliers under fuzzy environments, and arranged the alternative suppliers at the end of the study by using the fuzzy AHP method to select suppliers for a firm producing TVs in Taiwan Sen et al. [73] used the fuzzy AHP and max-min approach for the primary selection of suppliers in the electrical-electronic industry in Turkey. While the fuzzy AHP method was used to determine the weights of the selected cost, quality, service, and reliability criteria, the max-min approach was used to describe the efficient supplier cluster according to the weighted criteria and non-parametric statistical test, and to maximise and minimise the supplier performance. The efficient supplier cluster was determined at the end of the study.

Kilincci and Onal [74] applied the fuzzy AHP method to select the best supplier in a firm that produces furniture-white goods in Turkey. Three alternative suppliers were assessed by this method, using the criteria that were obtained from the experience and research of experts in the production planning department. The supplier with the highest priority weight was selected as the best supplier. Khorasani and Bafruei [75] selected the best

supplier in the health sector of Iran. First, the most important criteria of supplier selection, such as price, quality, service, organisation, and technical issues, were determined through literature research. The best supplier was then selected through the use of fuzzy AHP, and they suggested that this method be used in combination with GP for future studies. Zeydan et al. [76] used fuzzy AHP, fuzzy TOPSIS, and DEA methods in their study of supplier selection and assessment in the automotive sector in Turkey. The fuzzy AHP method was applied to calculate the weights of the determined supplier selection criteria; the weights that were obtained from here were transferred to the fuzzy TOPSIS method, and suppliers were selected and assessed by using the results in the DEA method as an output. Punniyamoorth et al. [77] conducted field research for supplier selection; structural equation modelling (SEM) and fuzzy AHP methods were used on the results obtained from those who responded to this field research. The primary step in the study was to generate hypotheses about the supplier selection criteria, and then the relationships between the SEM and criteria and suppliers were revealed. Finally, suppliers were arranged according to their priority weights with the help of fuzzy AHP. Kannan et al. [78] applied fuzzy AHP, fuzzy TOPSIS, and fuzzy multi-objective linear programming (MOLP) to solve the problem of supplier selection and order allocation for an automobile manufacturing company in Iran. Kar [79] used fuzzy AHP and fuzzy GP for the solution supplier selection problem. Rezaei et al. [80] used fuzzy AHP to evaluate suppliers according to main criteria and sub-criteria.

4.3 Fuzzy ANP

Razmi et al. [81] used the fuzzy ANP method for supplier selection. Four alternative suppliers were assessed according to six criteria, and alternative suppliers were arranged with the help of the method applied in the study. A sensitivity analysis was also conducted at the end of the study. Tuzkaya et al. [82] used the fuzzy ANP and fuzzy PROMETHEE methods in their study of supplier selection in the furniture white goods sector. Four alternative suppliers were assessed and arranged with this hybrid model, according to the six predetermined criteria for supplier selection. A sensitivity analysis was also conducted at the end of the study. Onut et al. [83] applied the fuzzy ANP and fuzzy TOPSIS methods to assess suppliers in the electrical-electronics sector in Turkey. Six suppliers were assessed with the fuzzy ANP method according to the predetermined criteria, and the criteria weights were obtained. Alternative suppliers were arranged by using the obtained weights in the fuzzy TOPSIS method, and a sensitivity analysis was conducted. In a hypothetical example of a firm that produces TVs, Wei et al. [84] used the fuzzy ANP method to select the best supplier from among the alternative suppliers. Vinodh et al. [85] used the fuzzy ANP method in their study of supplier selection in the electrical-electronics sector in India. In their study, three alternative suppliers were assessed under five supplier selections, and at the end of the study alternative suppliers were arranged and a sensitivity analysis was conducted. Buyukozkan and Cifci [86] used the fuzzy ANP method for supplier selection in a firm that operates in the furniture white goods sector in Turkey. Five alternative suppliers were assessed according to five criteria for supplier selection, and alternative suppliers were arranged. A sensitivity analysis was also conducted at the end of the study. Lin [87] used an integrated fuzzy ANP and fuzzy MOLP model for supplier evaluation and selection. Dargi et al. [88] used the fuzzy ANP method to evaluate suppliers for semi-assembly parts of an automobile manufacturer in Iran.

4.4 Fuzzy SMART

Chou and Chang [89] used the fuzzy SMART approach to the supplier selection problem in a firm operating in the IT sector in Taiwan, according to five qualitative and quantitative criteria. In their study, three alternative suppliers were discussed and five decision-makers made assessments according to the selected criteria. At the end of the study, alternative suppliers were arranged according to their total crisp values, and a sensitivity analysis was conducted. They also suggested in their study that it would be convenient to use the SMART method for supplier selection in future studies.

4.5 Fuzzy quality function deployment (QFD)

Bevilacqua et al. [90] suggested a new method that transfers the approach of typical QFD to the house of quality (HOQ) method in supplier selection. They applied this method as

fuzzy HOQ for the supplier selection of a firm operating in the automotive sector, and then they re-arranged the alternative suppliers at the end of the study. Amin and Razmi [91] used a fuzzy model that is integrated with the QFD for the selection of suppliers who provide internet services in the informatics sector in Iran. At the end of the study, alternative suppliers were arranged and a sensitivity analysis was conducted.

4.6 Fuzzy adaptive resonance theory (ART)

Keskin et al. [92] used the fuzzy ART method for selecting convenient material suppliers who purchase rod and tie-rod components for an automotive production company. A decision-making committee, consisting of a group leader and the quality, purchase, production, and finance departments, determined fifteen selection criteria, and these were assessed for ten alternative suppliers. At the end of the study, the best suppliers were arranged and then grouped into different categories.

4.7 Fuzzy set theory (FST) and the Dempster Shafer theory of evidence (DST)

Deng and Chan [93] proposed a MCDM methodology that combines FST and DST in the best supplier selection. First, the proposed method used linguistic items modelled as fuzzy numbers to represents experts' subjective opinions, in addition to crisp numbers to rank the performance of each criterion. At the end of their study, alternative suppliers arranged according to discounting coefficient of their.

4.8 Logarithmic fuzzy preference programming (LFPP)

Wang and Chin [94] applied the method of LFPP to select a transportation firm in the transportation logistics sector in Turkey. Suppliers' priority weights were calculated as a result of the assessments, which were performed in light of the three main criteria that had been predetermined.

4.9 Fuzzy multi-objective programming (MOP)

Amid et al. [95] used the fuzzy MOP method for supplier selection in a hypothetical example. In their study, cost, quality, service, and capacity were considered as the supplier selection criteria. The study was based on three basic objectives: minimising the net costs, decreasing rejected products, and minimising delivery delays. In order to attain these goals, three different conditions were considered in the study; as a consequence, results were obtained for the goals that were to be attained for these three conditions. Nazari-Shirkouhi et. al [96] used an interactive two-phase fuzzy MOLP model to solve a supplier selection problem with multiple price levels and multiple products.

After reviewing the literature, the hybrid methods used in supplier selection are presented in Figure 4.

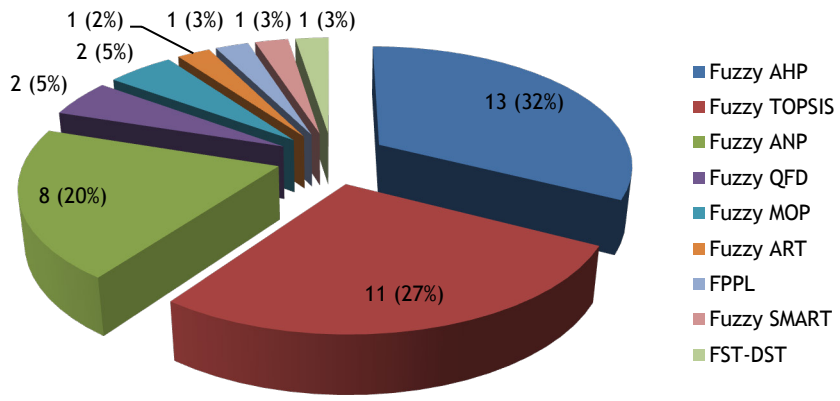

Figure 4: Hybrid fuzzy methods used in supplier selection (see online for colour version)

From Figure 4, it is noted that fuzzy AHP, fuzzy TOPSIS, and fuzzy ANP are frequently used in the hybrid fuzzy methods, and that the use of hybrid fuzzy methods has become widespread over the last decade.

It is worth highlighting that in fuzzy TOPSIS, attributed values are represented by fuzzy numbers. Using this method, the decision-makers' fuzzy assignments with different rating viewpoints and the trade-offs among different criteria are considered in the aggregation procedure to ensure more accurate decision-making [83].

After reviewing the literature, the sector-based distribution of the methods used in supplier selection is presented in Figure 5.

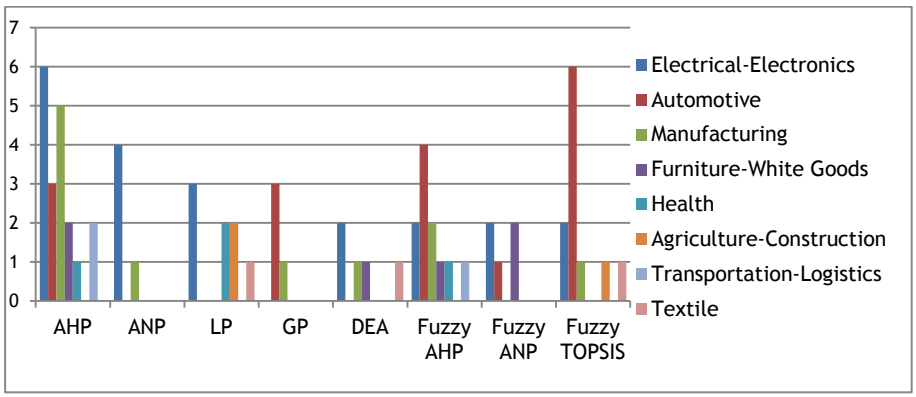

Figure 5: Sector-based distribution of the methods used in supplier selection (see online for colour version)

From Figure 5, it follows that while AHP is mostly used in the electrical-electronics and manufacturing sectors, ANP is mainly used in the electrical-electronics sector, and GP, fuzzy AHP, and fuzzy TOPSIS are often used in the automotive sector.

On the other hand, examining the supplier selection criteria presented in Figure 6, the rates of use are as follows: quality is 22 per cent, delivery is 17 per cent, cost is 15 per cent, and price is 14 per cent.

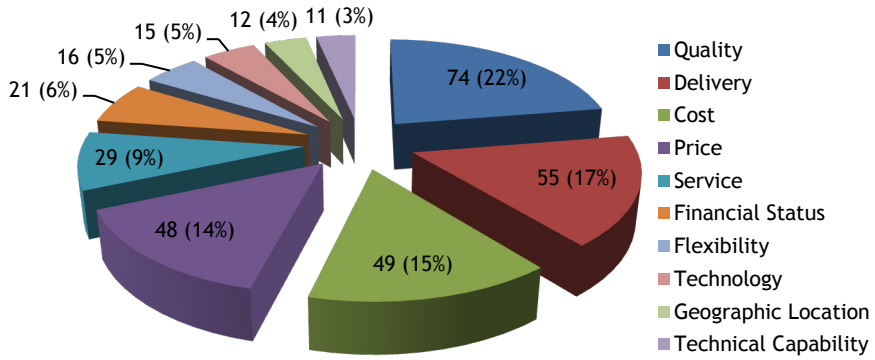

Figure 6: Supplier selection criteria (see online for colour version)

The chronological summary of the literature review addressing MCDM methods used in supplier selection and their sector-based application can be seen in the table presented in the Appendix.

5 IMPLICATIONS OF THE LITERATURE REVIEW AND CONCLUSION

Together with increasing global competition, enterprises encounter the pressure of reducing their production and material costs in order to sustain competitive advantage. For this reason, supplier selection has become very important. As one of the MCDM problems, supplier selection problems are frequently encountered within supply chain management. Furthermore, the determination of the convenient criteria and methods, and a clear expression of interactions, is very important for solving these problems. Scientific methods should be used in the supplier selection process in order to determine enterprises' preferences accurately. Otherwise, suppliers who do not meet the determined objectives might be selected.

In this study, a literature review was conducted on MCDM methods that were used between 2001 and 2014 for the supplier selection problem. Altogether, 91 studies were examined. The methods that were used for supplier selection were separated into three main groups: individual, hybrid, and hybrid-fuzzy methods.

Examining the resulting tables, AHP is mostly used in the individual and hybrid methods; fuzzy AHP, fuzzy TOPSIS, and fuzzy ANP are mostly used in the hybrid fuzzy methods; and the use of hybrid fuzzy methods has become widespread for the last decade.

Examining the sector-based distribution of the reviewed studies on methods used in supplier selection, it becomes evident that supplier selection studies are predominantly conducted in the electrical-electronics and automotive sectors. Since the products these two sectors produce generally consist of many components, the selection of suppliers with whom they should cooperate to provide these components is very important for the producers in these sectors.

Regarding the distribution of sector-based applications of methods used in supplier selection, it was revealed that AHP was mostly used in the electrical-electronics and manufacturing sector, ANP was used in the electrical-electronics sector, fuzzy AHP was used equally in the electrical-electronics and manufacturing sectors, and GP, fuzzy AHP, and fuzzy TOPSIS were used in the automotive sector.

This study is regarded as an important guide for researchers and performers who will conduct studies of the supplier selection problem, especially in seeking to understand the frequency of the supplier selection criteria and methods being used in supplier selection, whether generally or sector-based.

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APPENDIX

Author(s)	Year	Method(s)	Sector-based Application	Supplier Selection Criteria
Karpak et al.	2001	GP	Manufacturing	Product cost, product quality, delivery reliability
Ghodsypour & O'Brien	2001	Mixed-integer non-linear programming	Hypothetical example	Price, order cost, timely delivery, capacity, perfect rate
Narasimhan et al.	2001	DEA	Electrical-electronics	Quality, price, delivery, performance of decreasing the cost
Talluri	2002	Binary-integer linear programming	Health	Price, quality, delivery
Sarkis & Talluri	2002	ANP	Manufacturing	Culture, technology, relation, cost, quality, time, flexibility
Muralidharan et al.	2002	AHP	Manufacturing	Quality, delivery, price, technical skill, financial condition, previous performance attitude, factorisation, flexibility, service
Barla	2003	SMART	Manufacturing	Subcontractor reliability, subcontractor skill, quality organisation, geographical position, financial situation, service
Talluri & Narasimhan	2003	Linear programming	Health	Unit price, timely delivery, rejection, late delivery
Chan	2003	AHP	Hypothetical example	Cost, quality, delivery, design
Chan & Chan	2004	AHP	Electrical-electronics	Cost, delivery, flexibility, innovation, quality, service
Choy et al.	2005	CBR	Manufacturing	Price, delivery, quality, innovation level, technology level, culture, commercial awareness, production flexibility, ease of communication
Liu & Hai	2005	AHP	Furniture white goods	Quality, responsibility, discipline, delivery, financial management, technical skill
Hong et al.	2005	Mixed-integer linear programming	Agriculture-construction	Number of the purchased goods, quality, price, amount

Bevilacqua et al.	2006	Fuzzy QFD	Automotive	Sector experience, quality system certificate, flexibility of respond to customer demands, financial determination, geographical position, skill of managing the online orders
Amid et al.	2006	Fuzzy MOP	Hypothetical example	Cost, quality, service, capacity
Yang & Chen	2006	AHP - GRA	Electrical-electronics	Quality, finance, customer service, production capacity, design technical skill, system of information technologies, capital turnover, cost, delivery
Percin	2006	AHP - GP	Automotive	Production skill, convenience quality, flexibility, delivery reliability, constant development programs, technical information sharing, technological coherence, skill of product innovation, organisational structure, publicity and position in the industry, financial power, management skills, performance background, geographical position, long-term relation, respond to complaints, communication systems, guarantee support, restoration and maintenance service
Bayazit	2006	ANP	Hypothetical example	Flexibility, timely delivery, price, delivery time, quality, market share, staff skill, process skill, senior management skill, financial skill
Narasimhan et al.	2006	MOP	Electrical-electronics	Direct cost, indirect coordination cost, quality, delivery reliability
Hou & Su	2006	AHP	Electrical-electronics	Quality, cost, technology, production skill, research development, delivery, geographical position, performance and service
Chen et al.	2006	Fuzzy TOPSIS	Manufacturing	Profit of the supplier, relation imminence, technological skill, quality, problem solving
Shyur & Shih	2006	ANP - TOPSIS	Hypothetical example	Timely delivery, product quality, cost, respond to the needs of customers, professionalism of the salesperson, quality of the relation with suppliers, technology
Liao & Rittscher	2007	GA	Hypothetical example	Cost, quality, delivery, flexibility
Xia & Wu	2007	AHP-multi-objective mixed-integer programming	Hypothetical example	Price, quality (technical level, mistakes, reliability), service (timely delivery, supply capacity, time for restoration alternation, guarantee period)
Sevkli et al.	2007	AHP - DEA	Furniture white goods	Transportation quality, delivery, cost, number of employees, organisational structure, education, number of technical staff, management commitment, quality planning, storage, development, publicity, imminence, price, patent, technical skill
Ramanathan	2007	AHP - DEA	Hypothetical example	Production costs, quality, technology, post-sales service
Huang & Keskar	2007	AHP - MAUT	Electrical-electronics	Reliability, respond to needs, flexibility, cost and finance, infrastructure and existence, security, environment
Florez-Lopez	2007	SOFM	Hypothetical example	Efforts of decreasing the cost, delivery delays, price, reliability, quality, respond to needs, commitment for development, delivery mistakes, fluctuation in the cost, order mistakes, timely communication, customer service, technical support
Chan et al.	2007	AHP	Transportation-logistics	Cost, supplier's satisfaction, quality, research-development, organisational culture, compatibility, realisation of the risk, security, environmental and educational issues, technological issue, financial issue

Gencer & Gurpınar	2007	ANP	Electrical-electronics	General knowledge of the supplier, organisational profile of the supplier, financial situation of the supplier, equipment status of the supplier, production skill of the supplier, material handling skill of the supplier, quality system certificate of the supplier, quality system documentation of the supplier
Chan & Kumar	2007	Fuzzy extended AHP	Manufacturing	Total cost of the product, product quality, service performance of the supplier, profile of the supplier, risk factor
Chou & Chang	2008	Fuzzy SMART	Informatics	Cost, quality, delivery, organisational culture and strategy, technical capacity
Ha & Krishnan	2008	AHP – DEA - ANN	Manufacturing	Production accessibility, intent of the quality management, outputs of the quality system, quality recruitment, respond to demands, timely delivery, organisational control, work plans, customer relations, internal control, data management
Ng	2008	Linear	Agriculture-	Supply diversity, quality, distance, delivery, price
Bottani & Rizzi	2008	Fuzzy AHP - Cluster analysis	Manufacturing	Customer satisfaction, technical and organisational skills, willingness of the supplier, interest of the supplier, economic value, amount of the annual order, waiting period
Kull & Talluri	2008	AHP - GP	Automotive	Risk value, delivery, cost, quality, flexibility, general reliance
Li et al.	2008	GRA	Hypothetical example	Product quality, service, delivery, price
Mendoza et al.	2008	AHP - GP	Hypothetical example	Flexibility, quality, price, service, delivery
Boran et al.	2009	Fuzzy TOPSIS	Automotive	Product quality, relation imminence, delivery performance, price
Amin & Razmi	2009	Fuzzy QFD	Informatics	Accessibility, reliability, security, speed, effective marketing and promotion, experience, financial power, management resolution, strategically association, support source, monthly salary, set-up fee, supply diversity
Razmi et al.	2009	Fuzzy ANP	Hypothetical example	Quality, end time, degree of the company, background of the company, economic condition of the company, price
Lee	2009	Fuzzy AHP	Electrical-electronics	Flexibility, quality, delivery, common growth, supplier's technology, relation structure, relation cost, product cost, supply restriction
Buyukozkan & Ersoy	2009	Fuzzy TOPSIS	Informatics	Technological skill, supplier's profit, relation imminence, total cost, service quality, publicity of the supplier
Wang et al.	2009	Fuzzy hierarchical TOPSIS	Hypothetical example	Cost, key quality characteristics, service
Kokangul & Susuz	2009	AHP - Non-linear integer	Automotive	Price performance, delivery performance, cooperation and development performance, quality
Wu et al.	2009	ANP - Mixed-integer programming	Electrical-electronics	Management quality, technical quality, operational quality, fixed cost, variable cost
Onut et al.	2009	Fuzzy ANP - Fuzzy TOPSIS	Electrical-electronics	Cost, references, product quality, delivery time, institutionalism, application time
Shahanaghi & Yazdian	2009	Fuzzy Group TOPSIS	Automotive	Cost, performance, quality
Tuzkaya et al.	2009	Fuzzy ANP - Fuzzy PROMETHEE	Furniture white goods	Environmental process management, pollution control, environmental and legal management, environmental costs, environmental image, environmental product.
Kuo et al.	2010	ANN – ANP - DEA	Electrical-electronics	Quality, cost, delivery, service, environment, common social Responsibility

Keskin et al.	2010	Fuzzy ART	Automotive	Production security, similar items that are produced, technical efficiency of employee and equipment, efficiency of the production capacity, available testing skill, skill of design and recruitment, raw material, financial skill for finding end products and other resources, price politics and convenience of payment periods, effective use of certificates, packaging, transportation and skill of logistic requirement, geographical position, job security and applications of worker health, environmental effects and
Awasthi et al.	2010	Fuzzy TOPSIS	Hypothetical example	Use of eco-friendly technology, use of eco-friendly material, market share of environmentalism, cooperation with environmental organisations, management commitment, commitment to environmental politics, eco-friendly research and development projects, employee training, simple process planning, design for the environment, environmental certification, control initiatives for pollution
Chamodrakas et al.	2010	AHP-based fuzzy preference	Hypothetical example	Quality, cost, delivery
Wei et al.	2010	Fuzzy ANP	Hypothetical example	Quality, service, reliability, cost
Liao et al.	2010	ANP	Electrical-electronics	Performance (quality, timely marketability), feedback (esteem, rate, finance), interaction (relation, behaviour, communication), production (creativity, price, time)
Sen et al.	2010	Fuzzy AHP - Max-min approach	Electrical-electronics	Cost, quality, service, reliability
Chen	2011	DEA - Fuzzy TOPSIS	Textile	Quality, technology a production, cost, organisational Management
Liao & Kao	2011	Fuzzy TOPSIS - GP	Electrical-electronics	Relation imminence, product quality, delivery skill, guarantee level, experiment process
Buyukozkan & Ciftci	2011	Fuzzy ANP	Furniture white goods	Time, cost, quality, flexibility
Vinodh et al.	2011	Fuzzy ANP	Electrical-electronics	Work enhancement, convenience dimension, quality, service, risks
Jolai et al.	2011	Fuzzy TOPSIS - GP	Automotive	Timely delivery, imminence of relations with suppliers, product quality of the supplier, technological skill of the supplier, price/cost
Aksoy & Ozturk	2011	ANN	Automotive	Quality, timely delivery performance, geographical position, price
Zeydan et al.	2011	Fuzzy AHP - Fuzzy TOPSIS - DEA	Automotive	New project management, supplier improvement, quality and environmental management, test and supervising management, management of restoration and prevention activities, production process management
Wang & Chin	2011	Fuzzy preference programming	Transportation-logistics	Economic factors, social factors, political conditions
Golmohammadi	2011	ANN	Automotive	Quality, delivery, technology, price, geographical position
Amid et al.	2011	AHP - Max-min fuzzy programming	Hypothetical example	Quality, net cost, service
Ozkok & Tiryaki	2011	Multi-objective linear supplier selection problem with multiple-item	Textile	Price, quality level, service quality level, upper limit of item quantity to be obtained from suppliers, upper limit of the rejected item quantity
Deng & Chan	2011	FST – DST	Hypothetical example	Late product delivery, cost, risk factor, service performance

Punniyamoorth et al.	2011	Structural Equation Modelling - Fuzzy AHP	Manufacturing	Management and organisation, quality, technical skill, conveniences and capacities of production, financial situation, distribution, service, relations, issues of security and environment, cost
Khorasani & Bafruei	2011	Fuzzy AHP	Health	Price, quality, service, organisation, technics
Mahdiloo et al.	2011	DEA	Hypothetical example	Total cost of transportations, number of monthly shipping, research-development costs, number of timely transportations, number of bills that are received from suppliers without mistake
Kilincci & Onal	2011	Fuzzy AHP	Furniture white goods	Supplier criteria (financial status, management, technical skill, quality systems, geographical condition, working with kanban approach), criteria of product performance (product price, packaging, product quality), criteria of service performance (delay time, technical support, professionalisation, follow-up)
Mafakheri et al.	2011	AHP - Dynamic programming	Hypothetical example	Price performance, delivery performance, environmental performance, quality
Asamoah et al	2012	AHP	Health	Quality, price, reliability/capacity
Lin	2012	Fuzzy ANP – Fuzzy MOLP	Hypothetical example	Price, quality, delivery, technique
Chen & Chao	2012	AHP - Consistent Fuzzy	Electrical-electronics	Suppliers general, price and delivery, quality, professional techniques conditions
Amin & Zhang	2012	Multi-objective mixed-integer linear programming	Electrical-electronics	Cost, delivery, experience, quality, part safety, lightweight, recyclable, process capability, design process, reduction of wastes, using clean technology
Bruno et al.	2012	AHP	Transportation-logistics	Process and product quality, service level, management and innovation, financial position
Kannan et al.	2013	Fuzzy AHP - Fuzzy TOPSIS -	Automotive	Cost, quality, delivery, technology capability, environmental competency
Rajesh & Malliga	2013	AHP-QFD	Manufacturing	Quality, cost, delivery
Nazari-Shirkouhi	2013	Fuzzy Multi-Objective Linear	Hypothetical example	A number of defective units, and late delivered units
Chen & Wu	2013	Modified Failure Mode And	Electrical-electronics	Cost, quality, deliverability, technology, productivity, service
Rouyendegh et al.	2014	Fuzzy TOPSIS - Multi-Choice GP	Agriculture-construction	Supply capacity, production, capacity, response time, production technology, price, warranty, procedural compliance, purchase transaction, communication system, quality, completed shipping document, quantity , on time delivery, financial position, location, reputation ,
Ware et al.	2014	Mixed-Integer Non-Linear Program (MINLP)	Hypothetical example	Generated data for supplier's capacity, organisation's demand for each part for both periods, unit part cost for each suppliers, fixed transportation cost, quality level of all parts for each suppliers in each period, unit penalty cost incurred, late delivery, unit delay cost incurred, data of all suppliers for all parts
Kar	2014	AHP-Fuzzy GP	Manufacturing	Product, delivery compliance, price, technological capability, production capability, financial position, e-transaction capability, consistency measures, consensus index
Rezaei et al.	2014	Fuzzy AHP	Transportation-logistics	Cost/price, product quality, delivery, financial stability, assortment, corporate social
Jadidi et al.	2014	Multi-Objective Optimization	Hypothetical example	Supplier capacity, price, defect rate, late delivery
Junior et al.	2014	Fuzzy TOPSIS-Fuzzy AHP	Automotive	Quality, price, delivery, supplier profile, supplier relationship
Dargi et al.	2014	Fuzzy ANP	Automotive	Quality, price, production capacity, technical capability& facility, service & delivery, reputation,
Dobos & Vörösmarty	2014	DEA	Hypothetical example	Lead time, quality, price, reusability, CO_2 emission
Safa et al.	2014	TOPSIS	Agriculture-construction	Price, lead time, performance, early payment