Supplier Selection using Multi-criteria Decision Making Approaches: A Current Review

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Abstract
Selection of supplier is one of the most important decisions in purchasing. An inappropriate decision on supplier may affect the whole supply chain management. Decision making can be a stressful process as the performance of potential suppliers is evaluated based on multi-criteria. Various multi-criteria decision making approaches have been proposed to solve supplier selection problem. The purpose of this paper is to provide a review of supplier selection using multi-criteria decision making approaches from 2009 to 2013. The present paper extends the previous reviews by gathering related articles appearing in the international journals and conferences proceedings. Two classifications of individual approaches and integrated approaches were made in this paper. This review aids the researchers and decision makers in applying the approaches effectively. From the observation, it was noticed that six papers or 19 percent were using individual approaches against 25 papers or 81 percent of integrated approaches. About 48 percent of approaches in the category of integrated approaches were decision making method based on fuzzy set theory. The reviews also notice that 25 out of 31 papers (81%) considered quality as the most important criterion in supplier selection process. This paper offers useful information for other researchers since it provides the latest evidence of decision making approaches in supplier selection.

Keywords: Supplier selection, multi-criteria decision making, review, integrated approaches

1. Introduction
Supplier selection has been widely recognized as one of the most important processes in the purchasing activities. Supplier selection is the process by which the buyer identifies, evaluates, and contracts with suppliers. The selection process involves the determination of quantitative and qualitative factors. It aims to select the best possible suppliers, which ensure business competitiveness, sustainability and success. Proper supplier selection would reduce purchase risk, maximize the overall profit, increase customer satisfaction, and build closeness relationships between buyers and suppliers [1][2]. The inaccurate selection of suppliers may affect the whole network of supply chain management. Liao and Kao [3] postulated that inappropriate decision will affect the entire supply chain since the position of supplier selection and its related tasks are at the front end in the supply chain process. Therefore, choosing the right suppliers become a key strategic step in businesses since the impacts are directly goes to manufactures. The challenges in selecting the right suppliers make supplier selection a fertile topic for operations and management science disciplines.

Generally, supplier selection involves more than one criterion and sometimes there will be conflict with each other [4]. The complexity in supplier selection was further emphasised by Wu et al. [5]. They relate supplier selection as a multi-criteria problem which includes both quantitative and qualitative factors. Furthermore, some of these factors are intangible and may cause diverse disagreements. Thus supply selection is one of the multi-criteria problems that eventually lead to process of decision making. Extensive multi-criteria decision making approaches have been proposed for supplier selection. It has been reported that there are at least three journal articles reviewing the literature regarding supplier evaluation and selection models [6][7][8]. These articles review the literature up to year 2000. Ho et al. [9] made an extensive review on the various multi-criteria decision making approaches in supplier selection from year 2000 to year 2008. Ho et al. [9] split the approaches into individual approaches,
integrated approaches and other approaches. More than ten approaches were listed for the category of individual approaches, thirteen approaches for integrated approaches, and seven approaches were categorized under other approaches. It seems that there was no clear cut separation between integrated approaches and other approaches because all approaches involved more than one approach. This paper extends reviews the literature of the multi-criteria decision making approaches for supplier selection from year 2009 to year 2013. The two of classifications made by Ho et al. [9] is retained. However, the class of ‘other approaches’ as suggested by Ho et al. [9] is now categorized under integrated approaches.

The rest of this paper is organized as follows. Section 2 and 3 describes the individual approaches and integrated approaches on supplier selection respectively. Section 4 analyses the most prevalently used approaches and discusses the most popular criteria. Conclusion is made in Section 5.

2. Individual approaches

A single approach that was using to solve supplier selection problem is defined as individual approach. For example, Baker and Talluri [10], Braglia and Petroni [11] and Narasimhan et al. [12] applied a single method of Data Envelop Analysis (DEA) to evaluate the efficiencies of alternative suppliers. More examples of individual approaches are Garfamy [13] and Ross et al. [14] where they applied DEA to measure the supplier performances. After 2009, there were few more research used individual approaches in evaluation of supplier selection. The following reviews are made according to the methods used.

2.1 Data envelopment analysis

To extend the research of supplier selection using DEA, Azadeh and Alem [15] were the first study that presents a flexible approach for supply chain risk and vendor selection that consist three types of vendor selection models in supply chains under uncertainty, certainty and probabilistic conditions. The purpose of their study was to present a flexibility of DEA, Fuzzy Data Envelopment Analysis (FDEA) and Chance Constraint Data Envelopment Analysis (CCDEA) in approaching vendor selection problem. In FDEA model they used the flexibly characteristics of $\alpha$ -cuts method to convert it into interval programming. In solving CCDEA model, two levels of probabilities were used.

2.2 ELECTRE

Birgun and Cihan [16] developed ELECTRE method which is Elimination Et Choice Translation Reality for supplier selection. This method has two important concepts where thresholds and outranking and also two main procedures; construction of one or several outranking relation(s) followed by an exploitation procedure. ELECTRE method can also support to choose the second best alternative among all of them.

2.3 Matter-element model

Tang et al. [17] studied the evaluation and selection of suppliers in tourism supply chain by adopting the extension engineering method. According to matter-element model, extension method and theory of correlation function, an entropy-weighted extension matter-element model for the comprehensive evaluation of supplier was built. The characteristics of this method are it is an easy operation, clear practical significance and precise evaluation results. Finally, this model is applied to the supplier selection problem of a certain tour operator company to verify the developed approach.
2.4 Linear physical programming

Mirakhorli, Farahani and Ramtin [18] presented a new approach that using linear physical programming (LPP) for supplier selection problems. With this approach, the decision makers can take their preferences into account in ranges of different degrees of desirability. For further research, they suggest to extend the model by considering more criteria.

2.5 Neural network

Wu [19] introduced suppliers' credit grade analysis index system in their works. They also designed a dynamic neural network-based supplier evaluation and selection model. This model and guide line system can solve supplier credit analysis general problem. Guide line system was used for supplier evaluation.

2.6 Artificial neural network

Xu and Qian [20] proposed artificial neural network (ANN)-based predictive model in supplier selection. Specifically, the usage of this model was during supplier’s bid price. Their purpose was to provide negotiation supports for demander in deciding the better current bid price to decrease meaningless negotiation times, improve efficiency, reduce procurement cost or shorten supplier selection lead-time.

3. Integrated approaches

Integrated approaches are defined as more than one approach was used to solve supplier selection problem. Sevkli et al. [21], for example, applied an integrated approach because AHP and DEA were used concurrently for solving supplier selection problem. AHP was used to derive local weights while DEA used to calculate the efficiency scores of dummy input that had a value of one for all decision making units. Mendoza et al. [22] presented an integrated AHP and goal programming (GP) approach to minimize a large number of potential suppliers to a manageable number, rank the alternative suppliers and also determine the optimal order quantity. Chan and Kumar [23] proposed fuzzy AHP for supplier selection with the usage of triangular fuzzy numbers and fuzzy synthetic extent analysis method to represent decision makers’ comparison judgment and to choose the final priority of different criteria. All of these MCDM approaches were using integrated approaches.

After 2009, there were few more research adopted an integrated approaches in supplier selection. The following reviews are made according to the methods used.

3.1 Taguchi loss function, TOPSIS and goal programming.

Sharma and Balan [24] dealt with an integrative approach considering Taguchi’s loss function, Technique for Order preference by similarity to ideal solution (TOPSIS) and multi criteria goal programming. The model is split up into three phases. In the first phase, the quality losses are identified using Taguchi’s loss function. In the second phase, suitable factors were identified with different weights from technique for order preference by similarly to ideal solution (TOPSIS) and in the third phase, a GP model was developed to identify the best performing supplier with the weights and the loss associates. The purpose of their paper is to integrate different criteria levels to select relatively better performing supplier.
3.2 Fuzzy AHP and fuzzy TOPSIS

Zouggari and Benyoucef [25] proposed two phases in solving supplier selection. Fuzzy-AHP was used in selecting supplier through four criteria in the first phase. Then, by using simulation based on fuzzy TOPSIS technique they quantitatively evaluated the criteria for order allocation among the selected suppliers.

3.3 Fuzzy preference and analytic network process

Lin [26] adopted the fuzzy analytic network process (FANP) to handle inconsistent and uncertain judgments in identify the best suppliers by considering the effects of interdependence among the selection criteria. This FANP was combination fuzzy preference programming (FPP) with ANP. In order to achieve optimal order quantity from the top suppliers under stochastic demand conditions with constraints of quality, FANP was integrated with fuzzy multi-objective linear programming (FMOLP).

3.4 Fuzzy TOPSIS and multi-choice goal programming

Liao and Kao [3] developed an integrated fuzzy TOPSIS and multi-choice goal programming (MCGP) to solve multi sourcing supplier selection problem. MCGP was used based on tangible constrains so the order quantities can be assigned to each supplier and also maximize the total value of procurement. Moreover, this integrated method had advantage that allows the decision makers to set multiple aspiration levels for supplier selection problems.

3.5 Fuzzy logic and triangular fuzzy numbers

Amin et al. [27] were the first one introduced SWOT (Strengths, Weaknesses, Opportunities and Threats) in supplier selection. To deal with vagueness of human thought, fuzzy logic and triangular fuzzy number were integrated with SWOT analysis. From the SWOT matrix, the managers can understand the position of suppliers in a competitive environment. They also proposed fuzzy linear programming to know how much should be purchased from each supplier. Therefore, this method was purposely used for only for company that wants to buy products from multiple suppliers.

3.6 Multi objective linear model and fuzzy sets

Yucel and Guneri [28] presented a new weighted additive fuzzy multi objective linear model (MOLM) approach. Trapezoidal fuzzy numbers were used to assess the weight of the factors. They applied distance measure between fuzzy positive and negative ideal rating to obtain weight value. Then, fuzzy multi objective linear model was developed to solve selection problem and assign optimum order quantities to each supplier.

3.7 Fuzzy set and AHP

Kilincici and Onal [29] applied fuzzy AHP to select the best supplier for a washing machine company in Turkey. The weights and alternatives were calculated using fuzzy AHP. They used macros in MS Excel for the calculation to avoid hand made errors during mathematical calculation.

Wang and Yang [30] used AHP and fuzzy compromise programming when considered quantity discounts in supplier selection. With the combination of these two methods, they generated a compromise solution that satisfied most configurations of decision makers’ preferences efficiently so that the purchasing quantities within a supplier base under the conditions of quantity discounts can be allocated.

Lee [31] constructed a fuzzy analytic hierarchy process (AHP) model with consideration of benefits, opportunities, costs and risks (BOCR) for supplier selection. Fuzzy set theory is integrated into the model to overcome the uncertainty and vagueness in human decision-making process.
3.8 Order weighted aggregation and AHP

Zhang [32] developed ordered weighted aggregation (OWA) operator to deal with the vagueness of decision makers. The important step of the OWA operator is to determine its associated weights. Therefore, AHP is used to calculate the weight of the criteria. The steps for AHP are similar with paper from Guang and Wenji [33]. With this merger, they used the method to solve supplier selection problem.

3.9 Data envelop analysis and mixed integer linear programming

Toloo and Nalchigar [34] proposed a new integrated approach of DEA in finding the best supplier with imprecise data. By considering both factors which are ordinal and cardinal data, the best supplier is selected. They identified the most efficient suppliers by only solving one mixed integer linear programming (MILP). Moreover from the proposed model, they also can use it in ranking the suppliers.

3.10 Fuzzy sets and TOPSIS

Sevkli et al. [35] presented a comparison between crisp and fuzzy TOPSIS. Triangular fuzzy number has been used in linguistic rating for fuzzy TOPSIS. Instead of closeness coefficient, they used closeness coefficient defuzzified in ranking the alternatives. The result showed that there were different in choosing the best alternatives between both methods.

3.11 AHP, entropy weight and TOPSIS

In 2009, researchers Guang and Wenji [33] have used analytical hierarchy process (AHP) and entropy value in weight part of TOPSIS method. They combined the subjective weight (AHP) and objective weight (entropy) and used it in TOPSIS to select the best supplier. The aimed of AHP is to get a single overall score by integrating different measures for ranking decision alternatives. The main characteristic of AHP is based on pair-wise comparison judgment. For the entropy method the corresponding weight can reflect the truth since the original information empowered should root directly in an objective environment.

3.12 VIKOR and fuzzy sets

Sanayei et al. [36] have developed the VIKOR (multi-criteria optimization and compromise solution) method to solve multiple criteria decision making (MCDM) problems with conflicting and non-commensurable criteria. The concept of fuzzy set theory and linguistic values were used to overcome uncertainty and qualitative factors. Supplier selection problem can be solved by using VIKOR method and MCDM model based on fuzzy set theory. This method has some advantages where not only the order of suppliers can be determined but also can evaluate and rate the suppliers. Besides, the method provides a systematic approach which can be easily extended to deal with other management decision making problems.

3.13 ELECTRE and fuzzy sets

Montazer et al. [37] have modified ELECTRE III from method [38] to use in fuzzy expert decision aiding system. Fuzzy notion have been utilized to address the uncertainty in evaluations and ranking of the alternatives. The fuzzy ELECTRE III method was used in final to rank the vendors.

3.14 Fuzzy-Bayesian

Ferreira and Borenstein [39] presented the integration of influence diagram and fuzzy logic to rank and evaluate suppliers. Their model gave advantages to managers in explore the strength and weakness of each alternative, assist the setting of priorities between various criteria, study the sensitivity of the
behavior of alternatives and identify a preferred course of action. Then, Bayesian method that included with fuzzy information was used to develop probabilistic learning in supplier selection problem.

3.15 Neural network and genetic algorithm

Golmohammadi et al. [40] developed a model using neural network (NN) to select suppliers, while a genetic algorithm (GA) was applied to generate weights and network architecture. The reason of the usage of GA was to obtain the benefit of a search technique for model structure and training.

3.16 DEA, decision tree and NN

Wu [41] presented a hybrid model that combined Data Envelopment Analysis (DEA), Decision Trees (DT) and Neural Networks (NNs) to evaluate supplier performance that aiming prediction accuracy rate and a favorable classification. This model has advantages that can deal with the complexity and multiple criteria and also can function as both a classification model and a regression model.

3.17 BPNN and grey correlation

Chen et al. [42] used BP neural network (BPNN) to calculate the weight of indexes for supplier selection. Before that, they transformed the triangular fuzzy numbers into crisp first. Then, to select the best supplier, grey correlation analysis has been used.

3.18 P-SVM and GA

In paper Xu and Xu [43], they proposed a method of potential support vector machines (P-SVM) with GA. P-SVM is used to select optimal classifier by exchanging the roles of data points and features. Then, based on one-against-one method the problem of multi-class can be solved. GA was applied to accomplish the appropriate parameters selection and to improve the performance of P-SVM. A comparison between P-SVM and standard SVM has been made and the result showed that P-SVM gave a better result than SVM.

3.19 FCM and fuzzy soft set

Xiao et al. [44] integrated the fuzzy cognitive map (FCM) and fuzzy soft set model in supplier selection problem. This method considered the dependent and feedback effect among criteria that depicted by using FCM and the uncertainties on decision making process with the usage of fuzzy soft set.

3.20 Fuzzy ANP and non-linear programming

Razmi et al. [45] developed a framework based upon analytic network process that can suitably model the quantitative and qualitative criteria that are involved in supplier selection. To handle with the vagueness and indeterminacy of data, fuzzy sets theory has been used. Moreover, a non-linear programming (LP) model was augmented to the proposed model to obtain the relative weights from fuzzy comparison matrices.

3.21 Fuzzy multi objective linear programming

Arikan [46] transformed a typical and a very well-known multi objective linear programming (MOLP) supplier selection model into convex fuzzy programming models with a single objective function that can reduce the dimension of the system and less computational complexity. By using an appropriate linear membership function, each fuzzy parameter was represented mathematically.
3.22 Interval valued-intuitionistic fuzzy sets and TOPSIS

Izadikhah [47] extended TOPSIS method for group decision making with Atanassov's [48] interval-valued intuitionistic fuzzy numbers is proposed to solve the supplier selection problem. Weights of criteria have been calculated using the decision matrix of each decision maker. Also, the normalized Hamming distance is proposed to calculate the distance between Atanassov's interval-valued intuitionistic fuzzy numbers.

3.23 AHP and taguchi loss function

Supplier selection is a multi-criteria decision-making process encompassing various tangible and intangible factors. Both risks and benefits of using a vendor in supply chain are identified for inclusion in the evaluation process. Ordoobadi [49] developed a decision model to help decision makers with selection of the appropriate supplier. Taguchi loss functions are used to measure performance of each supplier candidate with respect to the risks and benefits. Analytical hierarchy process (AHP) is used to determine the relative importance of these factors to the decision maker. The weighted loss scores are then calculated for each supplier by using the relative importance as the weights. The composite weighted loss scores are used for ranking of the suppliers. The supplier with the smallest loss score is recommended for selection.

3.24 Entropy and TOPSIS

Traditional TOPSIS algorithm has a weakness on evaluation attributes weighting and distance in traditional TOPSIS algorithm. Since Zhao and Ren [49] have noticed the weakness, therefore they have improved the TOPSIS algorithm. They defined a new relative closeness to the ideal solution and the selection of alternative achieved by using the relative entropy between an alternative and the ideal solution between the alternative and the negative-ideal solution. The advantages of this method are it takes the subjective and objective weights together and it improves the accuracy of the decision making.

3.24 Fuzzy AHP

Jin and Liu [49] have proposed a model that can be applied to improve and help the decision maker in choosing the optimal supplier combination during solving supplier selection problem. They used fuzzy AHP systematic approaches to the alternative selection and justification problems using the concepts of fuzzy set theory and hierarchical structure analysis. Finally they compared the result of fuzzy AHP and the original AHP in solving supplier selection problem and it showed that, the result was same. They mentioned that the proposed model is a good method for the performance evaluation of multi-attribute and multiple goals.

3.25 ANP and RBF

In the era of low carbon economy, green supplier selection is an important issue in chemical industry. By considering traditional supplier selection and environmental factors as the criteria, Zhou et al. [49] proposed a method based on analytic network process (ANP) and radial basis function (RBF) neural network. The ANP was used to derive all the weight of the criteria. Then, with the weight of criteria they incorporated the RBF neural network into alternatives selection process. Implied knowledge is extracted from the training data during RBF neural network training procedure. Therefore, the integrated method possesses dynamic assessment capability.

Reviews of supplier selection approaches are summarized in Table 1.
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There are several possible observations out of these reviews.

4. Discussions

According to Ho et al. [9] individual approaches were slightly more popular than integrated approaches. However, for the year 2009 – 2013, this trend is no longer maintained. Integrated approaches seem more popular than individual approaches. Six paper or 19 percent were using individual approaches against 25 papers or 81 percent of integrated approaches. It was noticed that the most popular approach in the category of integrated approaches is fuzzy set theory -based approaches (48%). Fuzzy
set theory approaches are more prevalent to overcome the uncertainty and the vagueness of human thought. Fuzzy set theory has been combined with other techniques, including ANP, Non-LP, MOLP, ELECTRE, Bayesian, SWOT, LP, TOPSIS and FCM. Comparatively, the integration of fuzzy set theory-AHP is the most popular.

In solving the supplier selection problem, selecting the criteria also play an important role. The most popular criterion in supplier selection is ‘quality’. Almost all authors which are 25 out of 31 papers (81%) considered ‘quality’ in supplier selection process. There are different kind of ‘quality’ have been found in the papers such as product quality, service quality and quality of acceptance levels, quality of product delivery, quality performance, service quality credence and quality certification system.

The second popular criterion is ‘price/cost’ (21 papers or 68%). Various ‘price/ cost’ related attributes also have been found in the papers, such as transportation cost, cost reduction capability, net price, cost reduction performance, cost of crushing, storage cost, cost of supplying, cost of shipment, unit cost and expected cost. The third most popular criterion is ‘delivery’ (13 papers or 42%). Its related attributes are delivery time, supplier’s delivery ratio, on-time delivery rate and transportation and delivery capabilities. As mentioned before, the most popular criterion is ‘quality’. This observation is consistent with Ho et al. [9]. However, for the second and third criteria, the result differs from Ho et al. [9] which found that the second popular criteria was ‘delivery’ followed by ‘price/cost’.

5. Conclusions

This paper has summarized the multi-criteria decision making approaches for supplier selection from year 2009 to year 2013. It was found that at least six individual approaches and twenty three integrated approaches were proposed to solve the supplier selection problem. It indicates that integrated approaches seem more popular than individual approaches for the studied period. The most prevalent integrated approach is the integration of fuzzy set theory and Analytic Hierarchy Process. What is interesting in this finding is that more than forty percent of integrated approaches are the approaches that based on fuzzy set theory. This finding suggests that in general, the applications of decision making approaches based on fuzzy set theory are widely accepted by researchers. It was also observed that ‘quality’ is the most popular criterion followed by ‘price/cost’. This finding seems to be consistent with Ho et al. [9]. With this review, it is hoped that more developments could be seen in future especially in exploring new integrated approaches that can support the decision in supplier selection.

6. Acknowledgement

This research is supported by the Fundamental Research Grant Scheme, Malaysian Ministry of Higher Education (no. 59243). This support is gratefully acknowledged.

7. References

