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Group decision making process for supplier selection with VIKOR under fuzzy environment

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ABSTRACT

During recent years, how to determine suitable suppliers in the supply chain has become a key strategic consideration. However, the nature of supplier selection is a complex multi-criteria problem including both quantitative and qualitative factors which may be in conflict and may also be uncertain. The VIKOR method was developed to solve multiple criteria decision making (MCDM) problems with conflicting and non-commensurable (different units) criteria, assuming that compromising is acceptable for conflict resolution, the decision maker wants a solution that is the closest to the ideal, and the alternatives are evaluated according to all established criteria. In this paper, linguistic values are used to assess the ratings and weights for these factors. These linguistic ratings can be expressed in trapezoidal or triangular fuzzy numbers. Then, a hierarchy MCDM model based on fuzzy sets theory and VIKOR method is proposed to deal with the supplier selection problems in the supply chain system. A numerical example is proposed to illustrate an application of the proposed model.

1. Introduction

In today's fierce competitive environment characterized by thin profit margins, high consumer expectations for quality products and short lead-times, companies are forced to take the advantage of any opportunity to optimize their business processes. To reach this aim, academics and practitioners have come to the same conclusion: for a company to remain competitive, it has to work with its supply chain partners to improve the chain's total performance. Thus, being the main process in the upstream chain and affecting all areas of an organization, the purchasing function is taking an increasing importance. Thus supply chain management and the supplier (vendor) selection process is an issue that received relatively large amount of attention in both academia and industry.

Supplier selection is a fundamental issue of supply chain area which heavily contributes to the overall supply chain performance. Particularly for companies who spend a high percentage of their sales revenue on parts and material supplies, and whose material costs represent a larger portion of total costs, savings from supplies are of particular importance. These, strongly urge for a more systematic and transparent approach to purchasing decision making, especially regarding the area of supplier selection. Selecting the suppliers significantly reduces the purchasing cost and improves corporate competitiveness, and that is why many experts believe that the supplier selection is the most important activity of a purchasing department. Supplier selection is the process by which suppliers are reviewed, evaluated, and chosen to become part of the company's supply chain. The overall objective of supplier selection process is to reduce purchase risk, maximize overall value to the purchaser, and build the closeness and long term relationships between buyers and suppliers (Chena, Lin, & Huangb, 2006).

Several factors affect a supplier's performance. Dickson (1966), Ellram (1990), Roa and Kiser (1980), Stamm and Golhar (1993) identified, respectively 60, 18, 13 and 23 criteria for supplier selection.

The supplier selection process is often in influenced by uncertainty in practice (de Boer, van der Wegen, & Telgen, 1998; Min, 1994). Due to strategic importance and involvement of various uncertainties and risks associated with the supplier selection process, several decision makers from departments other than purchasing such as production, finance, and marketing are very often involved in the decision making process for supplier selection process. Therefore, some scholars emphasized the need for a rational and systematic group decision making process for supplier selection (de Boer et al., 1998). In essential; the supplier selection problem in supply chain system is a group decision making combination of several and different criteria with different forms of uncertainty (Chena et al., 2006). Hence this problem is a kind of multiple criteria decision making problem (MCDM) which requires MCDM methods for an effective problem-solving. Due to nature of the problem, the techniques of MCDM are coherently derived to

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Table 1
Supplier selection methods and examples.

Category	Approach	Example
MADM	AHP	Narasimhan (1983), Barbarosoglu and Yazgaç (1997); Nydick and Hill (1992), Tam (2001), Lee et al. (2001), Liu and Hai (2005)
	ANP	Sarkis and Talluri (2002)
	MAUT	Min (1994)
	Outranking method	de Boer et al. (1998)
	TOPSIS	Chena et al. (2006)
Mathematical programming	LP	Pan (1989)
	GP	Bufa and Jackson (1983), Karpak et al. (1999)
	MIP	Weber and Ellram (1993), Chaudhry et al. (1993)
	DEA	Weber (1996)
Statistical/ probabilistic		Hinkle et al. (1969)
		Ronen and Trietsch (1998)
		Soukup (1987)
Artificial intelligence	Neural Networks	Albino and Garavelli (1998), Choy et al. (2002)
	Case-based reasoning	Cook (1997)
	Expert System	Vokurka et al. (1996)
Hybrid and innovative approaches	AHP–LP	Ghodsypour and O'Brien (1998)
	ANP–MIP	Demirtas and Üstün (n.d)
	ANP–TOPSIS	Shyur and Shih (2006)
	Fuzzy–QFD	Bevilacqua et al. (2006)

manage it. de Boer, Labro, and Morlacchi (2001) and Aissaoui, Haouari, and Hassini (2007) gave a good review and classification of the methods for supporting supplier selection. We can roughly divide these methods into six main categories: multi-attribute decision making (MADM), multi-objective decision making and mathematical programming (MP), statistics/probabilistic approaches, intelligent approaches, hybrid approaches and others. Six categories, each with their own related approaches and examples, are listed in Table 1.

Methods of the first category concentrate on selection activities. They select a limited and countable number of predetermined alternatives through multiple attributes or criteria. These methods involves multi attribute utility theory (MAUT), outranking methods, analytical hierarchy process (AHP) and its sophisticated version, analytical network process (ANP) and technique for order performance by similarity to ideal solution (TOPSIS). Among these methods, it is difficult to obtain a mathematical representation of the decision maker's utility function for using MAUT (Opricovic & Tzeng, 2007). The outranking methods are normally not used for the actual selection of alternatives, but they are very suitable for the initial screening process (to categorize alternatives into acceptable or unacceptable). After the screening process another method must be used to get a full ranking or actual recommendations among the alternatives (Loken, 2007). Also AHP and ANP have their own problems: rank reversal and difficulty in accommodating a great many candidates. The other method in this category, TOPSIS, is discussed in Section 2.

The methods in the second category optimize the interactions and tradeoffs among different factors of interest by considering constraints and different issues like discount, single or multiple sourcing and logistic costs; which allow the buyer to make an effective decision usually by determining the best order quantity/period from the suitable supplier/suppliers. Several optimization methods such as goal programming, linear programming, mixed integer and data envelopment analysis have been applied in this area. A significant problem with using mathematical programming methods is that most of them are too complex for practical use by operating managers. The other fallback of these methods is their lack to consider qualitative factors. Furthermore the methods in this category are mainly used in multiple sourcing environments for assigning order quantities between supplier/suppliers.

Statistical studies incorporate uncertainty; there are not many articles in the literature that utilize statistics in the supplier selection process. The published statistical models only accommodate for uncertainty with regard to one criterion at a time (de Boer et al., 2001).

Artificial Intelligence (AI) based models are based on computer-aided systems that in one way or another can be trained by a purchasing expert or historic data, however, the complexity of the system is not suitable for enterprises to solve the issue efficiently without high capability in advanced computer programs.

The fifth category is hybrid and innovative methods which authors integrate one or more methods together to utilize their both advantages. However the disadvantages of combined methods affect the effectiveness of hybrid models.

In other way the VIKOR method, a recently introduced new MCDM method developed to solve multiple criteria decision making (MCDM) problems with conflicting and non-commensurable (different units) criteria (Opricovic & Tzeng, 2007), may provide the basis for developing supplier selection models that can effectively deal with characteristics of this problem. In this paper, we used the concept of fuzzy set theory and linguistic values to overcome uncertainty and qualitative factors. Then, a hierarchy MCDM model based on fuzzy sets theory and VIKOR method is proposed to deal with the supplier selection problems in the supply chain system.

The rest of this paper is structured as follows. In the next section, an overview and background of the VIKOR method is presented. In Section 3, an overview of the concepts of the fuzzy approach is given. Section 4 will focus on the proposed model. Then a numerical example is illustrated in Section 5. In the final section, some conclusions are drawn for the study.

2. VIKOR method

Opricovic (1998), Opricovic and Tzeng (2002) developed VIKOR, the Serbian name: VlseKriterijumska Optimizacija I Kompromisno Resenje, means multi-criteria optimization and compromise solution (Chu, Shyu, Tzeng, & Khosla, 2007). The VIKOR method was developed for multi-criteria optimization of complex systems (Opricovic & Tzeng, 2004). This method focuses on ranking and selecting from a set of alternatives, and determines compromise solutions for a problem with conflicting criteria, which can help the decision makers to reach a final decision. Here, the compromise solution is a feasible solution which is the closest to the ideal, and a compromise means an agreement established by mutual concessions (Opricovic & Tzeng, 2007). It introduces the multi-criteria ranking index based on the particular measure of "closeness" to the "ideal" solution (Opricovic, 1998).

According to (Opricovic & Tzeng, 2004) the multi-criteria measure for compromise ranking is developed from the PL_p-metric used as an aggregating function in a compromise programming method (Yu, 1973). The various J alternatives are denoted as $a_1, a_2, \ldots, a_J$. For alternative a_j, the rating of the i th aspect is denoted by f_{ij}, i.e. f_{ij} is the value of i th criterion function for the alternative a_j; n is the number of criteria. Development of the VIKOR method started with the following form of L_p-metric:

$$L_{p,j} = \left\{ \sum_{i=1}^{n} [w_i(f_i^* - f_{ij})/(f_i^* - f_i^-)]^p \right\}^{1/p}, \quad (1)$$
$$1 \leqslant p \leqslant \infty; \quad j = 1, 2, \ldots, J.$$

Within the VIKOR method $L_{1,j}$ (as S_j in Eq. (15)) and $L_{\infty,j}$ (as R_j in Eq. (16)) are used to formulate ranking measure. $L_{1,j}$ is interpreted as 'concordance' and can provide decision makers with information about the maximum group utility' or 'majority'. Similarly, $L_{\infty,j}$ is interpreted as 'discordance' and provides decision makers with information about the minimum individual regret of the 'opponent'.

Also TOPSIS, another MCDM method, is based on aggregating function representing "closeness to ideal". In TOPSIS the chosen alternative should have the "shortest distance" from the ideal solution and the "farthest distance" from the "negative-ideal". The TOPSIS method introduces two reference points, but it does not consider the relative importance of the distances from these points. These two MCDM methods use different kinds of normalization to eliminate the units of the criterion functions, whereas the VIKOR method uses linear normalization, the TOPSIS method uses vector normalization. The normalized value in the VIKOR method does not depend on the evaluation unit of criterion function, whereas the normalized values by vector normalization in the TOPSIS method may depend on the evaluation unit (Chu et al., 2007).

3. Fuzzy approach

In dealing with a decision process, the decision maker is often faced with doubts, problems and uncertainties. In other words natural language to express perception or judgment is always subjective, uncertain or vague. To resolve the vagueness, ambiguity and subjectivity of human judgment, fuzzy sets theory (Zadeh, 1965) was introduced to express the linguistic terms in decision making (DM) process. Bellman and Zadeh (1970) developed fuzzy multi-criteria decision making (FMCDM) methodology to resolve the lack of precision in assigning importance weights of criteria and the ratings of alternatives regarding evaluation criteria.

The logical tools that people can rely on are generally considered the outcome of a bivalent logic (yes/no, true/false), but the problems posed by real-life situations and human thought processes and approaches to problem-solving are by no means bivalent (Tong & Bonissone, 1980). Just as conventional, bivalent logic is based on classic sets, fuzzy logic is based on fuzzy sets. A fuzzy set is a set of objects in which there is no clear-cut or predefined boundary between the objects that are or are not members of the set. The key concept behind this definition is that of "membership": any object may be a member of a set "to some degree"; and a logical proposition may hold true"to some degree". Each element in a set is associated with a value indicating to what degree the element is a member of the set. This value comes within the range $[0,1]$, where 0 and 1, respectively, indicate the minimum and maximum degree of membership, while all the intermediate values indicate degrees of "partial" membership (Bevilacqua, Ciarapica, & Giacchetta, 2006).

This approach helps decision makers solve complex decision making problems in a systematic, consistent and productive way (Carlsson & Fuller, 1996) and has been widely applied to tackle DM problems with multiple criteria and alternatives (Wang & Chang, 2007). In short, fuzzy set theory offers a mathematically precise way of modeling vague preferences for example when it comes to setting weights of performance scores on criteria. Simply stated, fuzzy set theory makes it possible to mathematically describe a statement like: "criterion X should have a weight of around 0.8" (de Boer et al., 2001).

Fuzzy set theory was also looked at as a tool for supplier selection because of the vagueness of the information related to parameters. Narasimhan (1983), Nydick and Hill (1992) handled imprecise information and uncertainty in supplier selection models for finding the best overall rating supplier. Amid, Ghodsypour, and O'Brien (2006) developed a fuzzy multi-objective linear model to overcome the vagueness of the information. Chena et al. (2006) developed a model that combines the use of fuzzy set theory and TOPSIS.

In the following, for the purpose of reference, some important definitions and notations of fuzzy sets theory from (Kaufmann & Gupta, 1991; Dubois & Prade, 1980; Zadeh, 1975; Chena et al., 2006) will be reviewed.

Let X be the universe of discourse, $X = \{x_1, x_2, \ldots, x_n\}$. A fuzzy set $\widetilde{A}$ of X is a set of order pairs, $\{(x_1, f_{\widetilde{A}}(x_1)), (x_2, f_{\widetilde{A}}(x_2)), \ldots, (x_n, f_{\widetilde{A}}(x_n))\}, f_{\widetilde{A}} : X \to [0,1]$ is the membership function of $\widetilde{A}$, and $f_{\widetilde{A}}(x_i)$ stands for the membership degree of x_i in $\widetilde{A}$. The value $f_{\widetilde{A}}$ is closer to 0, the degree is low. The value $f_{\widetilde{A}}$ is closer to 1, the degree is high.

A fuzzy set $\widetilde{A}$ of the universe of discourse X is convex if and only if for all x_1, x_2 in X, $f_{\widetilde{A}}(\lambda x_1 + (1-\lambda)x_2) \geqslant \min[f_{\widetilde{A}}(x_1), f_{\widetilde{A}}(x_2)]$, where $\lambda \in [0,1], x_1, x_2 \in X$.

The height of a fuzzy set is the largest membership grade attained by any element in that set. A fuzzy set $\widetilde{A}$ in the universe of discourse X is called normalized when the height of $\widetilde{A}$ is equal to 1. A fuzzy number is a fuzzy subset in the universe of discourse X that is both convex and normal.

Fuzzy membership function has more types. This paper adopts the type of a trapezoidal fuzzy number. A positive trapezoidal fuzzy number $(\text{PTFN})_c$ can be defined as (a_1, a_2, a_3, a_4), shown in Fig. 1. The membership function $\mu_{\widetilde{A}}(x)$ is defined as:

$$\mu_{\widetilde{A}}(x) = \begin{cases} 0, & x < a_1, \\ \frac{x-a_1}{a_2-a_1}, & a_1 \leqslant x \leqslant a_2, \\ 1, & a_2 \leqslant x \leqslant a_3, \\ \frac{x-a_4}{a_3-a_4}, & a_3 \leqslant x \leqslant a_4, \\ 0, & x > a_3. \end{cases} \quad (2)$$

A non-fuzzy number r can be expressed as (r, r, r, r). By the extension principle, the fuzzy sum $\oplus$ and fuzzy subtraction $\ominus$ of any two trapezoidal fuzzy numbers are also trapezoidal fuzzy numbers; but the multiplication $\otimes$ of any two trapezoidal fuzzy numbers is only an approximate trapezoidal fuzzy number. Given any two positive trapezoidal fuzzy numbers, $\tilde{a} = (a_1, a_2, a_3, a_4), \tilde{b} = (b_1, b_2, b_3, b_4)$ and a positive real number r, some main operations of fuzzy numbers $\widetilde{A}$ and $\widetilde{B}$ can be expressed as follows:

$$\widetilde{A} \oplus \widetilde{B} = [a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4], \quad (3)$$

$$\widetilde{A} \ominus \widetilde{B} = [a_1 - b_1, a_2 - b_2, a_3 - b_3, a_4 - b_4], \quad (4)$$

$$\widetilde{A} \otimes \widetilde{B} \cong [a_1 b_1, a_2 b_2, a_3 b_3, a_4 b_4], \quad (5)$$

$$\widetilde{A} \otimes r \cong [a_1 r, a_2 r, a_3 r, a_4 r]. \quad (6)$$

The operations of $\vee$(max) and $\wedge$(min) are defined as follow:

$$\widetilde{A}(\vee)\widetilde{B} = (a_1 \vee b_1, a_2 \vee b_2, a_3 \vee b_3), \quad (7)$$

$$\widetilde{A}(\wedge)\widetilde{B} = (a_1 \wedge b_1, a_2 \wedge b_2, a_3 \wedge b_3). \quad (8)$$

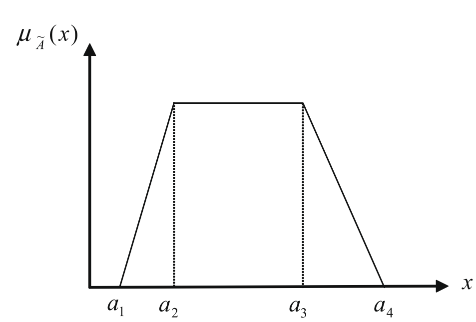

Fig. 1. Trapezoidal fuzzy number $\widetilde{A}$.

Also the crisp value of the fuzzy number $\widetilde{A}$ based on Center of Area (COA) method can be expressed by following relation:

$$defuzz(\widetilde{A}) = \frac{\int x \cdot \mu(x)dx}{\int \mu(x)dx} = \frac{\int_{a_1}^{a_2}\left(\frac{x-a_1}{a_2-a_1}\right)\cdot x\,dx + \int_{a_2}^{a_3} x\,dx + \int_{a_3}^{a_4}\left(\frac{a_4-x}{a_4-a_3}\right)\cdot x\,dx}{\int_{a_1}^{a_2}\left(\frac{x-a_1}{a_2-a_1}\right)dx + \int_{a_3}^{a_3} dx + \int_{a_3}^{a_4}\left(\frac{a_4-x}{a_4-a_3}\right)dx} = \frac{-a_1a_2 + a_3a_4 + \frac{1}{3}(a_4-a_3)^2 - \frac{1}{3}(a_2-a_1)^2}{-a_1 - a_2 + a_3 + a_4}. \quad (9)$$

4. Proposed method for supplier selection

A systematic approach to extend the VIKOR is proposed to solve the supplier selection problem under a fuzzy environment in this section. In this paper the importance weights of various criteria and the ratings of qualitative criteria are considered as linguistic variables. Because linguistic assessments merely approximate the subjective judgment of decision makers, we can consider linear trapezoidal membership functions to be adequate for capturing the vagueness of these linguistic assessments.

In fact, supplier selection in supply chain system is a group multiple criteria decision making (GMCDM) problem, which may be described by means of the following sets (Chena et al., 2006):

1. a set of K decision makers called $E = \{D_1, D_2, \ldots, D_K\}$;
2. a set of m possible suppliers called $A = \{A_1, A_2, \ldots, A_m\}$;
3. a set of n criteria, $C = \{C_1, C_2, \ldots, C_n\}$, with which supplier performances are measured;
4. a set of performance ratings of $A_i (i = 1, 2, \ldots, m)$ with respect to criteria $C_j (j = 1, 2, \ldots, n)$, called $X = \{x_{ij}, i = 1, 2, \ldots, m, j = 1, 2, \ldots, n\}$

The main steps of the algorithms are:

4.1. Identify the objectives of the decision making process and define the problem scope

Decision making is the process of defining the decision goals, gathering relevant information and selecting the optimal alternative (Hess & Siciliano, 1996). Thus, the first step is defining the decision goal that here is to evaluate and select a favorable supplier/s. Making precise statement of the problem will help to narrow it. Giving clear and careful thought to this first step is very vital to selecting process. The way in which the process is defined will deterministic the character of all the other steps.

In this step, the scope of the problem is defined in terms of the product/service to be outsourced, time frame for outsourcing, justification of decision, constraints in the supplier selection process, available alternative sources to choose from etc. Then the objectives of supplier selection is derived from various areas of organization impacted by the decision, e.g. assembly line, supplier quality assurance department, finance group, logistics department etc. and aligning them with the overall organizational goals.

4.2. Arrange the decision making group and define and describe a finite set of relevant attributes

As mentioned previously, in supplier evaluation and selection process several people and experts from different functional areas within the company are involved. So with considering the problem scope defined in previous section and its entire dimension, we must form a group of decision makers.

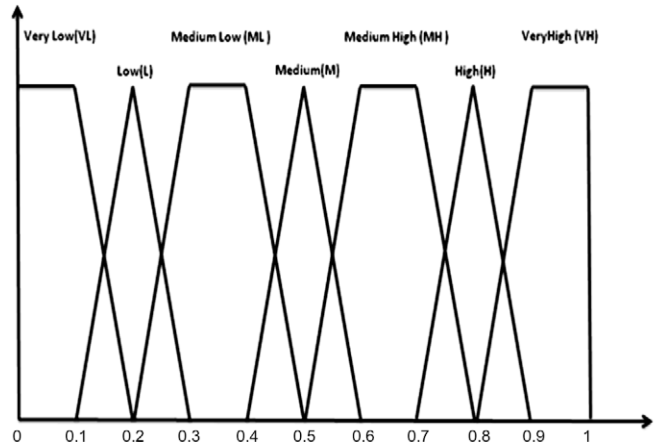

Fig. 2. Linguistic variables for importance weight of each criteria.

Supplier selection first requires identification of decision attributes (criteria) then evaluation scales/metrics are determined in order to measure appositeness of supplier. These criteria must be defined according to the corporate strategies, company's competitive situation, the level of buyer–supplier integration (Ghodsypour & O'Brien, 1998) and type of product which be outsourced. Then with considering sub-criteria for each main criterion, hierarchical form called "value tree" is structured.

4.3. Identify the appropriate linguistic variables

In this step we must define the appropriate linguistic variables for the importance weight of criteria, and the fuzzy rating for alternatives with regard to each criterion these linguistic variables can be expressed in positive trapezoidal fuzzy numbers, as in Figs. 1 and 2. It is suggested in this paper that the decision makers use the linguistic variables shown in Figs. 1 and 2 to evaluate the importance of the criteria and the ratings of alternatives with respect to qualitative criteria. For example, the linguistic variable "Medium High (MH)" can be represented as (0.5; 0.6; 0.7; 0.8), the membership function of which is:

$$\mu_{Medium\ High}(x) = \begin{cases} 0, & x < 0.5, \\ \frac{x-0.5}{0.6-0.5}, & 0.5 \leqslant x \leqslant 0.6, \\ 1, & 0.6 \leqslant x \leqslant 0.7, \\ \frac{x-0.8}{0.7-0.8}, & 0.7 \leqslant x \leqslant 0.8, \\ 0, & x > 0.8. \end{cases} \quad (10)$$

4.4. Pull the decision makers' opinions to get the aggregated fuzzy weight of criteria, and aggregated fuzzy rating of alternatives and construct a fuzzy decision matrix

Let the fuzzy rating and importance weight of the k th decision maker be $\tilde{x}_{ijk} = (x_{ijk1}, x_{ijk2}, x_{ijk3}, x_{ijk4})$ and $\tilde{w}_{jk} = (\tilde{w}_{jk1}, \tilde{w}_{jk2}, \tilde{w}_{jk3}, \tilde{w}_{jk4})$; $i = 1, 2, \ldots, m, j = 1, 2, \ldots, n$, respectively. Hence, the aggregated fuzzy ratings $(\tilde{x}_{ij})$ of alternatives with respect to each criterion can be calculated as:

$$\tilde{x}_{ij} = (x_{ij1}, x_{ij2}, x_{ij3}, x_{ij4}), \quad (11)$$

where

$$x_{ij1} = \min_k\{x_{ijk1}\}, \quad x_{ij2} = \frac{1}{K}\sum_{k=1}^{K} x_{ijk2}, \quad x_{ij3} = \frac{1}{K}\sum_{k=1}^{K} x_{ijk3}, \quad x_{ij4} = \max_k\{x_{ijk4}\}.$$

The aggregated fuzzy weights $(\tilde{w}_j)$ of each criterion can be calculated as:

$$\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3}, w_{j4}), \tag{12}$$

where

$$w_{j1} = \min_k\{w_{jk1}\}, \quad w_{j2} = \frac{1}{K}\sum_{k=1}^{K} w_{jk2}, \quad w_{j3} = \frac{1}{K}\sum_{k=1}^{K} w_{jk3},$$
$$w_{j4} = \max_k\{w_{jk4}\}.$$

A supplier selection problem can be concisely expressed in matrix format as follows:

$$\widetilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix}, \quad \widetilde{W} = [\tilde{w}_1 \quad \tilde{w}_2 \quad \cdots \quad \tilde{w}_n],$$

where $\tilde{x}_{ij}$ the rating of alternative A_i with respect to C_j, $\tilde{w}_j$ the importance weight of the jth criterion holds, $\tilde{x}_{ij} = (x_{ij1}, x_{ij2}, x_{ij3}, x_{ij4})$ and $\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3}, w_{j4}); i = 1, 2, \ldots, m, j = 1, 2, \ldots, n$ are linguistic variables can be approximated by positive trapezoidal fuzzy numbers.

4.5. Defuzzify the fuzzy decision matrix and fuzzy weight of each criterion into crisp values

Deffuzzify fuzzy decision matrix and fuzzy weight of each criterion into crisp values using COA defuzzification relation proposed in Section 3 (Relation 9).

4.6. Determine the best f_j^* and the worst f_j^- values of all criterion ratings, $j = 1, 2, \ldots, n$

$$f_j^* = \max_i x_{ij}; \tag{13}$$
$$f_j^- = \min_i x_{ij}. \tag{14}$$

4.7. Compute the values S_i and R_i by the relations

$$S_i = \sum_{j=1}^{n} w_j (f_j^* - f_{ij}) / (f_i^* - f_i^-), \tag{15}$$

$$R_i = \max_j w_j (f_j^* - f_{ij}) / (f_i^* - f_i^-). \tag{16}$$

4.8. Compute the values Q_i by the relations

$$Q_j = v(S_i - S^*)/(S^- - S^*) + (1 - v)(R_i - R^*)/(R^- - R^*), \tag{17}$$

where $S^* = \min_i S_i, S^- = \max_i S_i, R^* = \min_i R_i, R^* = \max_i R_i$ and v is introduced as a weight for the strategy of maximum group utility, whereas $1 - v$is the weight of the individual regret.

4.9. Rank the alternatives, sorting by the values S, R and Q in ascending order

4.10. Propose as a compromise solution the alternative $(A^{(1)})$ which is the best ranked by the measure Q (minimum) if the following two conditions are satisfied

C1. Acceptable advantage:

$$Q(A^{(2)}) - Q(A^{(1)}) \geqslant DQ, \tag{18}$$

where $A^{(2)}$is the alternative with second position in the ranking list by $Q; DQ = 1/(J-1)$.

C2. Acceptable stability in decision making:

The alternative $A^{(1)}$ must also be the best ranked by **S** or/and **R**. This compromise solution is stable within a decision making process, which could be the strategy of maximum group utility (when $v > 0.5$ is needed), or "by consensus"$v \approx 0.5$, or "with veto" $(v < 0.5)$. Here, v is the weight of decision making strategy of maximum group utility.

If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of

- Alternatives $A^{(1)}$ and $A^{(2)}$ if only the condition C2 is not satisfied, or
- Alternatives $A^{(1)}, A^{(2)}, \ldots, A^{(M)}$ if the condition C1 is not satisfied; $A^{(M)}$ is determined by the relation $Q(A^{(M)}) - Q(A^{(1)}) < DQ$ for maximum M (the positions of these alternatives are "in closeness").

5. Numerical example

The proposed model has been applied to a supplier selection process of a firm working in the field of automobile part manufacturing in the following steps:

Step 1: The Company desires to select a suitable supplier to purchase the key components of its new product. After preliminary screening, five candidate suppliers (S1, S2, S3, S4, and S5) remain for further evaluation.

Step 2: A committee of three decision makers, D1; D2 and D3, has been formed to select the most suitable supplier. The following criteria have been defined:
- Product quality
- On-time delivery
- Price/cost
- Supplier's technological level
- Flexibility

Step 3: Three decision makers use the linguistic weighting variables shown in Fig. 2 to assess the importance of the criteria. The importance weights of the criteria determined by these three decision makers are shown in Table 2. Also the decision makers use the linguistic rating variables shown in Fig. 3 to evaluate the ratings of candidates with respect to each criterion. The ratings of the five suppliers by the decision makers under the various criteria are shown in Table 3.

Step 4: The linguistic evaluations shown in Tables 2 and 3 are converted into trapezoidal fuzzy numbers. Then the aggregated weight of criteria and aggregated fuzzy rating of alternatives is calculated to construct the fuzzy decision matrix and determine the fuzzy weight of each criterion, as in Tables 4 and 5.

Table 2
Importance weight of criteria from three decision makers.

Criteria	Decision makers		
	D1	**D2**	**D3**
C1	H	H	H
C2	VH	VH	H
C3	VH	VH	VH
C4	H	H	MH
C5	H	H	H

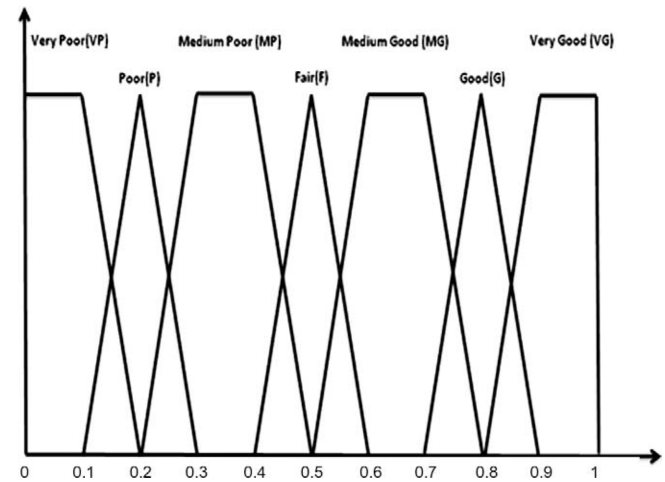

Fig. 3. Linguistic variables for ratings.

Table 3
Ratings of the five suppliers by the decision makers under the various criteria.

		Suppliers	Criteria				
			C1	**C2**	**C3**	**C4**	**C5**
Decision maker	D_1	**S1**	G	MG	G	G	G
		S2	G	VG	MP	G	VG
		S3	VG	MG	F	VG	G
		S4	G	G	MG	G	G
		S5	MG	MG	MG	MG	MG
	D_2	**S1**	G	MG	G	G	G
		S2	G	VG	F	VG	MG
		S3	VG	G	F	VG	VG
		S4	G	G	MG	G	G
		S5	MG	G	MG	MG	MG
	D_3	**S1**	VG	VG	G	G	G
		S2	G	VG	MP	VG	VG
		S3	G	G	F	VG	G
		S4	G	MG	G	G	VG
		S5	MG	G	MG	G	MG

Step 5: The crisp values for decision matrix and weight of each criterion are computed as shown in Table 6.

Step 6: The best and the worst values of all criterion ratings are determined as follows:

$$f_1^* = 0.87,\quad f_2^* = 0.92,\quad f_3^* = 0.80,\quad f_4^* = 0.92,\quad f_5^* = 0.85,$$
$$f_1^- = 0.65,\quad f_2^- = 0.72,\quad f_3^- = 0.40,\quad f_4^- = 0.70,\quad f_5^- = 0.65.$$

Steps 7 and 8: The values of **S**, **R** and **Q** are calculated for all suppliers as Table 6.

Step 9: The ranking of the suppliers by **S**, **R** and **Q** in decreasing order is shown in Table 7.

Step 9: As we see in Table 6, the supplier $\mathbf{S_3}$ is the best ranked by **Q**. Also the conditions **C**1 and **C**2 are

Table 5
Crisp values for decision matrix and weight of each criterion.

	Criteria				
	C1	**C2**	**C3**	**C4**	**C5**
Weight	0.80	0.87	0.92	0.72	0.80
S1	0.85	0.75	0.80	0.80	0.80
S2	0.80	0.92	0.40	0.87	0.79
S3	0.87	0.72	0.50	0.92	0.85
S4	0.80	0.72	0.70	0.80	0.85
S5	0.65	0.72	0.65	0.70	0.65

Table 6
The values of **S**, **R** and **Q** for all suppliers.

	Suppliers				
	S1	**S2**	**S3**	**S4**	**S5**
S	1.40	1.59	1.56	1.75	3.53
R	0.73	0.92	0.87	0.87	0.87
Q	0.00	0.46	0.45	0.49	0.91

Table 7
The ranking of the suppliers by **S**, **R** and **Q** in decreasing order.

	Ranking suppliers				
	1	2	3	4	5
By **S**	**S1**	**S3**	**S2**	**S4**	**S5**
By **R**	**S1**	**S3**	**S4**	**S5**	**S2**
By **Q**	**S1**	**S3**	**S2**	**S4**	**S5**

satisfied ($Q_{S1} - Q_{S3} \geqslant \frac{1}{5-1}$ and $\mathbf{S_3}$ is best ranked by **R** and **S**). So is $\mathbf{S_3}$ is the best choice.

6. Conclusion

Many practitioners and academics have emphasized the advantages of supply chain management. In order to increase the competitive advantage, many companies consider that a well-designed and implemented supply chain system is an important tool. Therefore being the main process in the upstream chain and affecting all areas of an organization, the supplier selection problem becomes the most important issue to implement a successful supply chain system.

The supplier selection problem is often influenced by uncertainty in practice, and in such situation fuzzy set theory is an appropriate tool to deal with this kind of problems. In real decision making process, the decision maker is unable (or unwilling) to express his preferences precisely in numerical values and the evaluations are very often expressed in linguistic terms. In this paper an extension of the VIKOR, a recently introduced MCDM method, in

Table 4
Aggregated fuzzy weight of criteria and aggregated fuzzy rating of alternatives.

	Criteria				
	C1	**C2**	**C3**	**C4**	**C5**
Weight	(0.70,0.80,0.80,0.90)	(0.70,0.87,0.93,1.00)	(0.80,0.90,1.00,1.00)	(0.50,0.73,0.77,0.90)	(0.70,0.80,0.80,0.90)
S1	(0.70,0.83,0.87,1.00)	(0.50,0.70,0.80,1.00)	(0.70,0.80,0.80,0.90)	(0.70,0.80,0.80,0.90)	(0.70,0.80,0.80,0.90)
S2	(0.70,0.80,0.80,0.90)	(0.80,0.90,1.00,1.00)	(0.20,0.37,0.43,0.60)	(0.70,0.87,0.93,1.00)	(0.50,0.80,0.90,1.00)
S3	(0.70,0.87,0.93,1.00)	(0.50,0.73,0.77,0.90)	(0.40,0.50,0.50,0.60)	(0.80,0.90,1.00,1.00)	(0.70,0.83,0.87,1.00)
S4	(0.70,0.80,0.80,0.90)	(0.50,0.73,0.77,0.90)	(0.50,0.67,0.73,0.90)	(0.70,0.80,0.80,0.90)	(0.70,0.83,0.87,1.00)
S5	(0.50,0.60,0.70,0.80)	(0.50,0.73,0.77,0.90)	(0.50,0.60,0.70,0.80)	(0.50,0.67,0.73,0.90)	(0.50,0.60,0.70,0.80)

fuzzy environment is proposed to deal with the both qualitative and quantitative criteria and select the suitable supplier effectively. It appears this method has some advantages which may be useful in dealing with supplier selection problem.

The proposed method is very flexible. Using this method not only enables us to determine the outranking order of suppliers, but also assess and rate the suppliers. These rating can be used in combination with mathematical programming and other methods to deal with supplier selection in multiple sourcing environments. Also the proposed method for supplier selection in fuzzy environment provides a systematic approach which can be easily extend to deal with other management decision making problems.

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