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Vendor Selection Using a New Fuzzy Group TOPSIS Approach

Kamran Shahanaghi, Seyed Ahmad Yazdian*
Department of Industrial Engineering, Iran University of Science and Technology, Narmak, Tehran, 16846-13114, Iran

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Abstract

Nowadays vendor (supplier) selection has turned to an important decision-making challenge for top decision-makers in companies; this is because an inappropriate decision affects not only that specific buyer but also the entire supply chain. In the real-world situations, due to incomplete and vague information, required data for decision making often can not be described deterministically, and are usually imprecise in nature. Therefore, in order to make more realistic decisions, fuzzy sets theory can be applied in such cases. In this paper, we propose a new fuzzy multiple criteria group decision making (FMCGDM) approach based on technique for order preference by similarity to ideal solution (TOPSIS) method for evaluating and selecting an appropriate vendor, where the ratings of each alternative and importance weight of each criterion are expressed in trapezoidal fuzzy numbers. Furthermore, we use the canonical representation of multiplication operation on three trapezoidal fuzzy numbers to construct the weighted normalized decision matrix. Finally, to clearly illustrate our approach a numerical example is conducted.
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Keywords: vendor selection, supply chain, fuzzy number, TOPSIS, MCDM, multiplication operation

1 Introduction

Selecting an appropriate supplier (or vendor, this two terms are used interchangeably throughout this paper) among different suppliers is a critical issue for top management. In industries that are concerned with large scale production the raw materials and component parts can equal up to 70% product cost. In such circumstances the purchasing department can play a key role in cost reduction, and supplier selection is one of the most important functions of purchasing management [20]. Therefore, using an appropriate method for this purpose is a crucial issue, supplier selection has been shown to be a multiple criteria decision making (MCDM) problem [39]. In a typical MCDM problem, multiple and usually conflicting criteria are simultaneously taken into account for making a decision. A comprehensive review and classification of the MCDM approaches for vendor selection has been carried out in [15].

As a pioneer in supplier selection problem, Dickson [17] identified 23 different criteria for this problem including quality, delivery, performance history, warranties, price, technical capability and financial position. After Dickson [17], this field attracted attentions of many researchers and consequently considerable methods and approaches proposed for this problem, among them are mathematical programming formulations. Moore and Fearon [30] described the possible use of linear programming (LP) without presenting the exact mathematical formulation. Bender *et al.* [3] proposed a mixed integer programming (MIP) to select vendors and their order quantities with the objective to minimize purchasing, inventory and transportation costs for the IBM company. Sharma *et al.* [33] and Buffa and Jackson [4] suggested a goal programming (GP) formulation for this problem. Gao and Tang [19] proposed a multi-objective linear programming model for decisions related to purchasing of raw materials in a large-scale steel plant in China. Weber *et al.* [38] presented data envelopment analysis (DEA) method for selecting vendors and their quota allocation. Farzipoor Saen [18] proposed an innovative method based on imprecise data envelopment analysis (IDEA) for supplier selection problem. Ghodsypour and O'Brien [20] and Wang *et al.* [37] proposed two-stage approaches for supplier selection and order allocation. They used the analytic hierarchy process (AHP) method to make the trade-off between concrete and vague factors and calculated suppliers' ratings. In the second stage of their approaches, using mathematical programming, they effectively selected the suppliers and allocated their orders. Demirtas and Ustun [13] proposed an integration of analytic network process (ANP) and multi-objective mixed integer linear programming (MOMILP) for choosing the best supplier and to determine their shipment allocations. They minimized total defect rate, total cost of purchasing, and maximized total value of purchasing (TVP).

* Corresponding author. Email: ah_yazdiyan@ind.iust.ac.ir (S.A. Yazdian).

From multiple attribute decision making (MADM) point of view, Yahya and Kingsman [40], Tam and Tummala [36], Handfield *et al.* [23] applied AHP method to determine priorities in selecting suppliers. Liu and Hai [29] proposed a method called the voting analytic hierarchy process (VAHP) for this problem. Shyur and Shih [34] proposed a hybrid model of ANP and TOPSIS for strategic vendor selection. Li *et al.* [28] proposed an approach based on grey theory. Almeida [2] proposed a multicriteria decision model based on utility function and ELECTRE method for outsourcing contracts selection. For further reading on supplier selection problems, interested reader may refer to Aissaoui *et al.* [1].

Most researches on vendor selection problem consider crisp and exact data which are usually far from real-world situations. In the real-world, the rating values of alternatives as well as importance weights of criteria usually have various types of vagueness, imprecision or subjectiveness, and one cannot always use the classical decision-making techniques for these problems. Therefore, the fuzzy sets theory provides a precious tool for taking these realities into account. In a fuzzy multiple criteria decision making (FMCDM), linguistic variables are used to express the subjectiveness and/or imprecision qualitative of a decision maker's assessments. A linguistic variable is a variable whose values are linguistic terms [6, 21, 41].

Just a few researchers have applied the fuzzy sets theory into supplier selection problem. Chen *et al.* [5] used fuzzy TOPSIS method, and Chou and Chang [12] introduced fuzzy SMART approach for supplier selection. On the other hand, Kumar *et al.* [26] used fuzzy programming approach for vendor selection, but they didn't incorporate intangible criteria in the decision process.

In recent years, TOPSIS [24] has been a favorable technique for solving MCDM problems. This is mainly for two reasons, 1) its concept is reasonable and easy to understand, and 2) in comparison with other MCDM methods, like AHP, it requires less computational efforts, and therefore can be applied easily. TOPSIS is based on the concept that the optimal alternative should have the shortest distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS).

Because of advantages of TOPSIS method, in this paper we propose a new fuzzy TOPSIS approach for vendor (supplier) selection problem. Chen *et al.* [5] introduced fuzzy sets theory to supplier selection problem, but they only investigated a three-level hierarchy problem, i.e., goal, criteria and alternatives. In this paper, to make a more detailed decision, we consider a four-level hierarchy problem- goal, criteria, sub-criteria and alternatives- furthermore we use the canonical representation of multiplication operation on three trapezoidal fuzzy numbers [11] to evaluate and rank alternative suppliers and to select the most promising one.

The rest of the paper is structured as follows. In Section 2 we present the canonical representation of multiplication operation based on the inverse function algorithmic representation method on three trapezoidal fuzzy numbers. In Section 3 we propose our fuzzy group TOPSIS approach to evaluate alternative suppliers. In Section 4 a numerical example for vendor selection problem (VSP) is conducted. Finally, in Section 5 conclusions are given.

2 Canonical Representation of Multiplication Operation on Fuzzy Numbers

Chou [10] proposed the canonical representation of multiplication operation on two triangular fuzzy numbers by the graded multiple integration representation method. In this section, we present the canonical representation of multiplication operation on three trapezoidal fuzzy numbers based on the inverse function arithmetic representation method, which was proposed by Chou [11] for solving marine transshipment container port selection problem, and this canonical representation will be applied to our fuzzy TOPSIS method for vendor selection problem in Section 3.

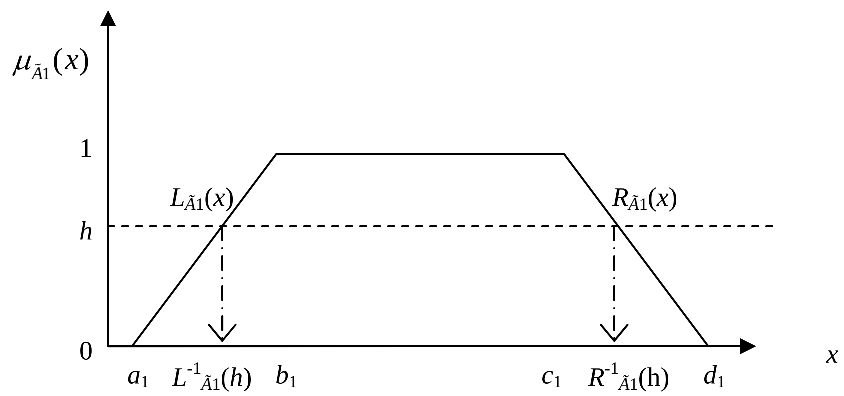

Figure 1: Trapezoidal fuzzy number $\tilde{A}_1 = (a_1, b_1, c_1, d_1)$

Suppose $\tilde{A}_1 = (a_1,b_1,c_1,d_1)$ is a trapezoidal fuzzy number as Figure 1. $L^{-1}_{\tilde{A}1}(h)$ and $R^{-1}_{\tilde{A}1}(h)$ are the inverse functions of the function $L_{\tilde{A}1}(x)$ and $R_{\tilde{A}1}(x)$ of $\tilde{A}_1$ at h-level, respectively. The membership function of $\tilde{A}_1$ is

$$\mu_{\tilde{A}1}(x)=\begin{cases}0, & x<a_1,\\ \dfrac{(x-a_1)}{(b_1-a_1)}, & a_1\le x\le b_1,\\ 1, & b_1\le x\le c_1,\\ \dfrac{(x-d_1)}{(c_1-d_1)}, & c_1\le x\le d_1,\\ 0, & x>d_1.\end{cases} \tag{1}$$

Since

$$L_{\tilde{A}1}(x)=\frac{(x-a_1)}{(b_1-a_1)},\quad a_1\le x\le b_1, \tag{2}$$

$$R_{\tilde{A}1}(x)=\frac{(x-d_1)}{(c_1-d_1)},\quad c_1\le x\le d_1, \tag{3}$$

we have

$$L^{-1}_{\tilde{A}1}(h)=a_1+(b_1-a_1)h,\quad 0\le h\le 1, \tag{4}$$

$$R^{-1}_{\tilde{A}1}(h)=d_1+(c_1-d_1)h,\quad 0\le h\le 1. \tag{5}$$

Similarly, suppose the membership function of $\tilde{A}_2=(a_2,b_2,c_2,d_2)$ is

$$\mu_{\tilde{A}2}(x)=\begin{cases}0, & x<a_2,\\ \dfrac{(x-a_2)}{(b_2-a_2)}, & a_2\le x\le b_2,\\ 1, & b_2\le x\le c_2,\\ \dfrac{(x-d_2)}{(c_2-d_2)}, & c_2\le x\le d_2,\\ 0, & x>d_2.\end{cases} \tag{6}$$

Since

$$L_{\tilde{A}2}(x)=\frac{(x-a_2)}{(b_2-a_2)},\quad a_2\le x\le b_2, \tag{7}$$

$$R_{\tilde{A}2}(x)=\frac{(x-d_2)}{(c_2-d_2)},\quad c_2\le x\le d_2, \tag{8}$$

one has

$$L^{-1}_{\tilde{A}2}(h)=a_2+(b_2-a_2)h,\quad 0\le h\le 1, \tag{9}$$

$$R^{-1}_{\tilde{A}2}(h)=d_2+(c_2-d_2)h,\quad 0\le h\le 1. \tag{10}$$

Finally, suppose the membership function of $\tilde{A}_3=(a_3,b_3,c_3,d_3)$ is

$$\mu_{\tilde{A}3}(x)=\begin{cases}0, & x<a_3,\\ \dfrac{(x-a_3)}{(b_3-a_3)}, & a_3\le x\le b_3,\\ 1, & b_3\le x\le c_3,\\ \dfrac{(x-d_3)}{(c_3-d_3)}, & c_3\le x\le d_3,\\ 0, & x>d_3.\end{cases} \tag{11}$$

Since

$$L_{\tilde{A}3}(x)=\frac{(x-a_3)}{(b_3-a_3)},\quad a_3\le x\le b_3, \tag{12}$$

$$R_{\tilde{A}3}(x)=\frac{(x-d_3)}{(c_3-d_3)},\quad c_3\le x\le d_3, \tag{13}$$

we have

$$L^{-1}_{\tilde{A}3}(h) = a_3 + (b_3 - a_3)h, \quad 0 \le h \le 1, \tag{14}$$

$$R^{-1}_{\tilde{A}3}(h) = d_3 + (c_3 - d_3)h, \quad 0 \le h \le 1. \tag{15}$$

The inverse function arithmetic representation method is defined as follows.

Definition ([11]**).** Let $P(\tilde{A}_1 \otimes \tilde{A}_2 \otimes \tilde{A}_3)$ be the representation of $\tilde{A}_1 \otimes \tilde{A}_2 \otimes \tilde{A}_3$. Then

$$\begin{aligned} P(\tilde{A}_1 \otimes \tilde{A}_2 \otimes \tilde{A}_3) = \int_0^1\int_0^1\int_0^1 \frac{1}{8}[&(h_{\tilde{A}1}L^{-1}_{\tilde{A}1}(h))(h_{\tilde{A}2}L^{-1}_{\tilde{A}2}(h))(h_{\tilde{A}3}L^{-1}_{\tilde{A}3}(h)) + (h_{\tilde{A}1}R^{-1}_{\tilde{A}1}(h))(h_{\tilde{A}2}L^{-1}_{\tilde{A}2}(h))(h_{\tilde{A}3}L^{-1}_{\tilde{A}3}(h)) \\ &+(h_{\tilde{A}1}L^{-1}_{\tilde{A}1}(h))(h_{\tilde{A}2}R^{-1}_{\tilde{A}2}(h))(h_{\tilde{A}3}L^{-1}_{\tilde{A}3}(h)) + (h_{\tilde{A}1}L^{-1}_{\tilde{A}1}(h))(h_{\tilde{A}2}L^{-1}_{\tilde{A}2}(h))(h_{\tilde{A}3}R^{-1}_{\tilde{A}3}(h)) \\ &+(h_{\tilde{A}1}L^{-1}_{\tilde{A}1}(h))(h_{\tilde{A}2}R^{-1}_{\tilde{A}2}(h))(h_{\tilde{A}3}R^{-1}_{\tilde{A}3}(h)) + (h_{\tilde{A}1}R^{-1}_{\tilde{A}1}(h))(h_{\tilde{A}2}L^{-1}_{\tilde{A}2}(h))(h_{\tilde{A}3}R^{-1}_{\tilde{A}3}(h)) \\ &+(h_{\tilde{A}1}R^{-1}_{\tilde{A}1}(h))(h_{\tilde{A}2}R^{-1}_{\tilde{A}2}(h))(h_{\tilde{A}3}L^{-1}_{\tilde{A}3}(h)) + (h_{\tilde{A}1}R^{-1}_{\tilde{A}1}(h))(h_{\tilde{A}2}R^{-1}_{\tilde{A}2}(h))(h_{\tilde{A}3}R^{-1}_{\tilde{A}3}(h))] \times \frac{dh_{\tilde{A}1}dh_{\tilde{A}2}dh_{\tilde{A}3}}{\left(\int_0^1 h_{\tilde{A}1}dh_{\tilde{A}1}\int_0^1 h_{\tilde{A}2}dh_{\tilde{A}2}\int_0^1 h_{\tilde{A}3}dh_{\tilde{A}3}\right)} \end{aligned} \tag{16}$$

$$\begin{aligned} = \int_0^1\int_0^1\int_0^1 \frac{1}{8}\{ &h_{\tilde{A}1}[a_1 + (b_1 - a_1)h_{\tilde{A}1}]h_{\tilde{A}2}[a_2 + (b_2 - a_2)h_{\tilde{A}2}]h_{\tilde{A}3}[a_3 + (b_3 - a_3)h_{\tilde{A}3}] \\ &+ h_{\tilde{A}1}[d_1 + (c_1 - d_1)h_{\tilde{A}1}]h_{\tilde{A}2}[a_2 + (b_2 - a_2)h_{\tilde{A}2}]h_{\tilde{A}3}[a_3 + (b_3 - a_3)h_{\tilde{A}3}] \\ &+ h_{\tilde{A}1}[a_1 + (b_1 - a_1)h_{\tilde{A}1}]h_{\tilde{A}2}[d_2 + (c_2 - d_2)h_{\tilde{A}2}]h_{\tilde{A}3}[a_3 + (b_3 - a_3)h_{\tilde{A}3}] \\ &+ h_{\tilde{A}1}[a_1 + (b_1 - a_1)h_{\tilde{A}1}]h_{\tilde{A}2}[a_2 + (b_2 - a_2)h_{\tilde{A}2}]h_{\tilde{A}3}[d_3 + (c_3 - d_3)h_{\tilde{A}3}] \\ &+ h_{\tilde{A}1}[a_1 + (b_1 - a_1)h_{\tilde{A}1}]h_{\tilde{A}2}[d_2 + (c_2 - d_2)h_{\tilde{A}2}]h_{\tilde{A}3}[d_3 + (c_3 - d_3)h_{\tilde{A}3}] \\ &+ h_{\tilde{A}1}[d_1 + (c_1 - d_1)h_{\tilde{A}1}]h_{\tilde{A}2}[a_2 + (b_2 - a_2)h_{\tilde{A}2}]h_{\tilde{A}3}[d_3 + (c_3 - d_3)h_{\tilde{A}3}] \\ &+ h_{\tilde{A}1}[d_1 + (c_1 - d_1)h_{\tilde{A}1}]h_{\tilde{A}2}[d_2 + (c_2 - d_2)h_{\tilde{A}2}]h_{\tilde{A}3}[a_3 + (b_3 - a_3)h_{\tilde{A}3}] \\ &+ h_{\tilde{A}1}[d_1 + (c_1 - d_1)h_{\tilde{A}1}]h_{\tilde{A}2}[d_2 + (c_2 - d_2)h_{\tilde{A}2}]h_{\tilde{A}3}[d_3 + (c_3 - d_3)h_{\tilde{A}3}]\} \times \frac{dh_{\tilde{A}1}dh_{\tilde{A}2}dh_{\tilde{A}3}}{\left(\int_0^1 h_{\tilde{A}1}dh_{\tilde{A}1}\int_0^1 h_{\tilde{A}2}dh_{\tilde{A}2}\int_0^1 h_{\tilde{A}3}dh_{\tilde{A}3}\right)} \end{aligned}$$

$$\begin{aligned} = \frac{1}{8}\Bigg\{ &\left[\frac{1}{2}a_1 + \frac{1}{3}(b_1 - a_1)\right]\left[\frac{1}{2}a_2 + \frac{1}{3}(b_2 - a_2)\right]\left[\frac{1}{2}a_3 + \frac{1}{3}(b_3 - a_3)\right] + \left[\frac{1}{2}d_1 + \frac{1}{3}(c_1 - d_1)\right]\left[\frac{1}{2}a_2 + \frac{1}{3}(b_2 - a_2)\right]\left[\frac{1}{2}a_3 + \frac{1}{3}(b_3 - a_3)\right] \\ &+ \left[\frac{1}{2}a_1 + \frac{1}{3}(b_1 - a_1)\right]\left[\frac{1}{2}d_2 + \frac{1}{3}(c_2 - d_2)\right]\left[\frac{1}{2}a_3 + \frac{1}{3}(b_3 - a_3)\right] + \left[\frac{1}{2}a_1 + \frac{1}{3}(b_1 - a_1)\right]\left[\frac{1}{2}a_2 + \frac{1}{3}(b_2 - a_2)\right]\left[\frac{1}{2}d_3 + \frac{1}{3}(c_3 - d_3)\right] \\ &+ \left[\frac{1}{2}a_1 + \frac{1}{3}(b_1 - a_1)\right]\left[\frac{1}{2}d_2 + \frac{1}{3}(c_2 - d_2)\right]\left[\frac{1}{2}d_3 + \frac{1}{3}(c_3 - d_3)\right] + \left[\frac{1}{2}d_1 + \frac{1}{3}(c_1 - d_1)\right]\left[\frac{1}{2}a_2 + \frac{1}{3}(b_2 - a_2)\right]\left[\frac{1}{2}d_3 + \frac{1}{3}(c_3 - d_3)\right] \\ &+ \left[\frac{1}{2}d_1 + \frac{1}{3}(c_1 - d_1)\right]\left[\frac{1}{2}d_2 + \frac{1}{3}(c_2 - d_2)\right]\left[\frac{1}{2}a_3 + \frac{1}{3}(b_3 - a_3)\right] + \left[\frac{1}{2}d_1 + \frac{1}{3}(c_1 - d_1)\right]\left[\frac{1}{2}d_2 + \frac{1}{3}(c_2 - d_2)\right]\left[\frac{1}{2}d_3 + \frac{1}{3}(c_3 - d_3)\right]\Bigg\} \times \frac{1}{(1/2)^3} \end{aligned}$$

$$\begin{aligned} = \Bigg\{ &\left(\frac{a_1+2b_1}{6}\right)\left(\frac{a_2+2b_2}{6}\right)\left(\frac{a_3+2b_3}{6}\right) + \left(\frac{d_1+2c_1}{6}\right)\left(\frac{a_2+2b_2}{6}\right)\left(\frac{a_3+2b_3}{6}\right) + \left(\frac{a_1+2b_1}{6}\right)\left(\frac{d_2+2c_2}{6}\right)\left(\frac{a_3+2b_3}{6}\right) + \left(\frac{a_1+2b_1}{6}\right)\left(\frac{a_2+2b_2}{6}\right)\left(\frac{d_3+2c_3}{6}\right) \\ &+ \left(\frac{a_1+2b_1}{6}\right)\left(\frac{d_2+2c_2}{6}\right)\left(\frac{d_3+2c_3}{6}\right) + \left(\frac{d_1+2c_1}{6}\right)\left(\frac{a_2+2b_2}{6}\right)\left(\frac{d_3+2c_3}{6}\right) + \left(\frac{d_1+2c_1}{6}\right)\left(\frac{d_2+2c_2}{6}\right)\left(\frac{a_3+2b_3}{6}\right) + \left(\frac{d_1+2c_1}{6}\right)\left(\frac{d_2+2c_2}{6}\right)\left(\frac{d_3+2c_3}{6}\right)\Bigg\} \end{aligned}$$

$$\begin{aligned} = &\left(\frac{a_1+2b_1}{6}\right)\left(\frac{a_2+2b_2}{6}\right)\left[\left(\frac{a_3+2b_3}{6}\right) + \left(\frac{d_3+2c_3}{6}\right)\right] + \left(\frac{d_1+2c_1}{6}\right)\left(\frac{a_2+2b_2}{6}\right) \times \left[\left(\frac{a_3+2b_3}{6}\right) + \left(\frac{d_3+2c_3}{6}\right)\right] \\ &+ \left(\frac{a_1+2b_1}{6}\right)\left(\frac{d_2+2c_2}{6}\right)\left[\left(\frac{a_3+2b_3}{6}\right) + \left(\frac{d_3+2c_3}{6}\right)\right] + \left(\frac{d_1+2c_1}{6}\right)\left(\frac{d_2+2c_2}{6}\right)\left[\left(\frac{a_3+2b_3}{6}\right) + \left(\frac{d_3+2c_3}{6}\right)\right] \end{aligned}$$

$$= \left\{\left(\frac{a_1+2b_1}{6}\right)\left[\left(\frac{a_2+2b_2}{6}\right) + \left(\frac{d_2+2c_2}{6}\right)\right] + \left(\frac{d_1+2c_1}{6}\right)\left[\left(\frac{a_2+2b_2}{6}\right) + \left(\frac{d_2+2c_2}{6}\right)\right]\right\} \times \left[\left(\frac{a_3+2b_3}{6}\right) + \left(\frac{d_3+2c_3}{6}\right)\right]$$

$$= \frac{1}{6}(a_1 + 2b_1 + 2c_1 + d_1) \times \frac{1}{6}(a_2 + 2b_2 + 2c_2 + d_2) \times \frac{1}{6}(a_3 + 2b_3 + 2c_3 + d_3).$$

Therefore, we will have the following canonical representation of multiplication operation on three trapezoidal fuzzy numbers:

$$P(\tilde{A}_1 \otimes \tilde{A}_2 \otimes \tilde{A}_3) = \frac{1}{6}(a_1 + 2b_1 + 2c_1 + d_1) \times \frac{1}{6}(a_2 + 2b_2 + 2c_2 + d_2) \times \frac{1}{6}(a_3 + 2b_3 + 2c_3 + d_3). \tag{17}$$

3 The Proposed Fuzzy Group TOPSIS Approach

The vendor selection can be considered as a group decision making problem because in addition to the senior manager, other major stakeholders in the company are engaged in this decision making process. In the real-life environment, usually a considerable extent of information for making strategic decisions is not known with certainty, and imprecise, indefinite, and subjective data and information are the inherent characteristics of such decision processes. Fuzzy sets theory might provide the flexibility to represent the imprecise/vague information resulting from the lacking of knowledge and information [6, 7, 25, 41]. Vendor selection problem is one of such decision processes, therefore fuzzy sets theory is employed to deal with this vagueness and imprecision.

In this paper the importance weights of criteria and the ratings of alternatives against each criterion are considered as linguistic variables. Here, we represent these linguistic variables as positive trapezoidal fuzzy numbers. In general, the importance weight of each criterion can be obtained by either direct assignment or indirectly using pairwise comparisons [8, 22]. In this paper, we assume that decision-makers use the linguistic variables shown in Figure 2 to directly evaluate the importance weight of each criterion and in Figure 3 to rate each alternative with respect to each criterion.

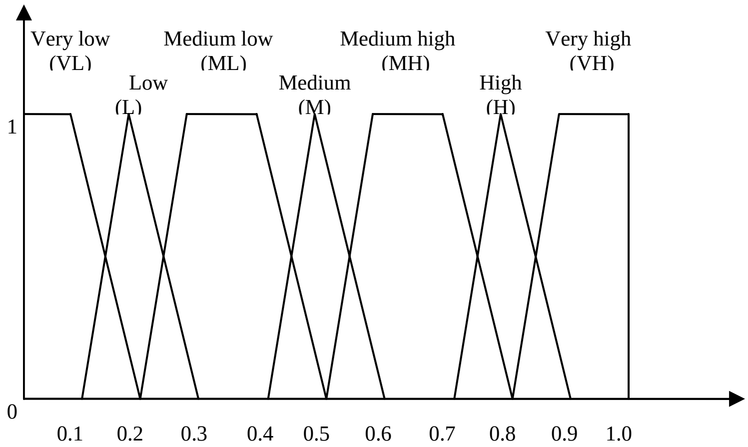

Figure 2: Linguistic variables for importance weight of each criterion

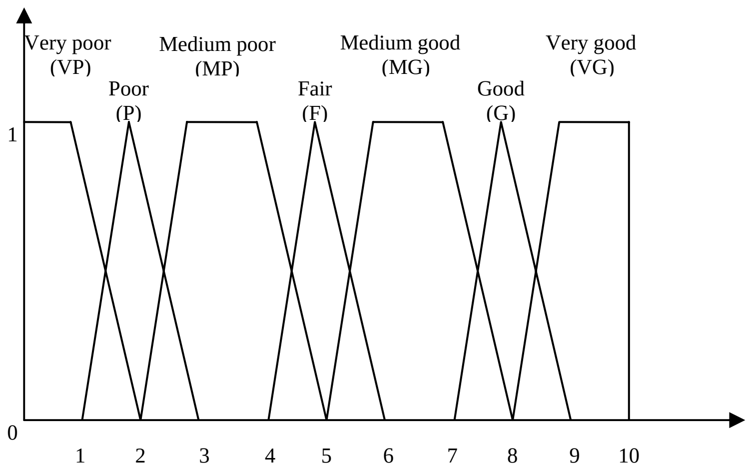

Figure 3: Linguistic variables for ratings of each alternative

Sets and parameters are as follows:

Assume

(i) $D = \{ D_1, D_2, ..., D_T \}$ is the set of *T* decision-makers;

(ii) $A = \{ A_1, A_2, ..., A_m \}$ is the set of *m* alternatives;

(iii) $C = \{ C_1, C_2, ..., C_n \}$ is the set of *n* criteria;

(iv) $S_j = \{S_1, S_2, \dots, S_{l_j}\}$ is the set of l_j sub-criteria of criterion j such that $\sum_{j=1}^{n} l_j = l$;

(v) $\tilde{x}_{ijk}^t$, $i=1,\dots,m$, $j=1,\dots,n$, $k=1,\dots,l_j$, $t=1,\dots,T$, is the fuzzy rating of alternative A_i $(i=1,\dots,m)$ with respect to criterion C_j $(j=1,\dots,n)$ and sub-criterion S_{jk} $(j=1,\dots,n;\ k=1,2,\dots,l_j)$ by decision-maker D_t $(t=1,2,\dots,T)$.

In addition, suppose $\tilde{w}_j^t = (w_{j1}^t, w_{j2}^t, w_{j3}^t, w_{j4}^t)$, $\tilde{u}_{jk}^t = (u_{jk1}^t, u_{jk2}^t, u_{jk3}^t, u_{jk4}^t)$ represent the fuzzy importance weights of criterion C_j $(j=1,\dots,n)$ and fuzzy importance weight of sub-criterion S_{jk} $(j=1,\dots,n;\ k=1,2,\dots,l_j)$ of criterion C_j, by decision-maker D_t $(t=1,2,\dots,T)$, respectively. Hence, the aggregated fuzzy importance weight ($\tilde{w}_j$) of each criterion, fuzzy importance weight ($\tilde{u}_{jk}$) of each sub-criterion k of criterion j, and fuzzy rating ($\tilde{x}_{ijk}$) of each alternative can be obtained as $\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3}, w_{j4})$, $\tilde{u}_{jk} = (u_{jk1}, u_{jk2}, u_{jk3}, u_{jk4})$, $\tilde{x}_{ijk} = (a_{ijk}, b_{ijk}, c_{ijk}, d_{ijk})$, respectively, where

$$w_{j1} = \min_t\{w_{j1}^t\}, \quad w_{j2} = \sum_{t=1}^{T} w_{j2}^t / T, \quad w_{j3} = \sum_{t=1}^{T} w_{j3}^t / T, \quad w_{j4} = \max_t\{w_{j4}^t\}; \tag{18}$$

$$u_{jk1} = \min_t\{u_{jk1}^t\}, \quad u_{jk2} = \sum_{t=1}^{T} u_{jk2}^t / T, \quad u_{jk3} = \sum_{t=1}^{T} u_{jk3}^t / T, \quad u_{jk4} = \max_t\{u_{jk4}^t\}; \tag{19}$$

$$a_{ijk} = \min_t\{a_{ijk}^t\}, \quad b_{ijk} = \sum_{t=1}^{T} b_{ijk}^t / T, \quad c_{ijk} = \sum_{t=1}^{T} c_{ijk}^t / T, \quad d_{ijk} = \max_t\{d_{ijk}^t\}. \tag{20}$$

The normalized fuzzy decision matrix can be represented as follows [9]:

$$\tilde{\mathbf{R}} = [\tilde{r}_{ijk}]_{m\times l}, \tag{21}$$

where

$$\tilde{r}_{ijk} = \left(\frac{a_{ijk}}{\max_i\{d_{ijk}\}}, \frac{b_{ijk}}{\max_i\{d_{ijk}\}}, \frac{c_{ijk}}{\max_i\{d_{ijk}\}}, \frac{d_{ijk}}{\max_i\{d_{ijk}\}} \right), \quad i=1,\dots,m, \quad j=1,2,\dots,n, \quad k=1,2,\dots,l_j. \tag{22}$$

Since we use linguistic variables, this kind of normalization is adequate for both benefit-type criteria and cost-type ones. For instance, assume that C_h is a cost-type criterion, and a decision-maker regarding this criterion evaluates alternatives A_k as "Poor", which means that its cost is relatively high, and A_l as "very good", which means that its cost is very low. According to Figure 3, the associated trapezoidal fuzzy ratings are (1,2,2,3) and (8,9,10,10), respectively. So, the normalized rating of alternative A_l with respect to criterion C_h will be larger than that of alternative A_k. Similarly, if C_b is a benefit-type criterion and decision-maker evaluates alternatives A_k and A_l as "good" with fuzzy rating of (7,8,8,9) and "fair" with fuzzy rating of (4,5,5,6), respectively, the normalized rating of alternative A_k, which regarding this benefit-type criterion is a better one, is greater than that of alternative A_l.

The normalization method mentioned above is used to preserve the property that the ranges of normalized fuzzy numbers belong to [0,1].

At this point by using the canonical representation of multiplication operation on trapezoidal fuzzy numbers, explained in section 2, we can calculate the weighted normalized decision matrix as follows:

$$v_{ijk} = P(\tilde{r}_{ijk} \otimes \tilde{u}_{jk} \otimes \tilde{w}_j) = \frac{1}{6}(a_{ijk} + 2b_{ijk} + 2c_{ijk} + d_{ijk}) \times \frac{1}{6}(u_{jk1} + 2u_{jk2} + 2u_{jk3} + u_{jk4}) \times \frac{1}{6}(w_{j1} + 2w_{j2} + 2w_{j3} + w_{j4}) \tag{23}$$

for $i=1,2,\dots,m, \quad j=1,2,\dots,n, \quad k=1,2,\dots,l_j$.

Therefore, we have

$$\mathbf{V} = [v_{ijk}]_{m\times l}, \quad i=1,2,\dots,m, \quad j=1,2,\dots,n, \quad k=1,2,\dots,l_j, \quad l=\sum_j l_j. \tag{24}$$

After constructing weighted normalized decision matrix, the positive ideal solution (A^*) and the negative-ideal solution (A^-) can be defined as

$$A^* = (v_{11}^*, v_{12}^*, \dots, v_{nl_n}^*), \tag{25}$$

$$A^- = (v_{11}^-, v_{12}^-, \dots, v_{nl_n}^-), \tag{26}$$

where

$$v_{jk}^* = \max_i\{v_{ijk}\}, \tag{27}$$

$$v_{jk}^- = \min_i\{v_{ijk}\} \tag{28}$$

for $i=1,2,\dots,m, \quad j=1,2,\dots,n, \quad k=1,2,\dots,l_j$.

The distance of each alternative from A^* and A^- can now be calculated as follows

$$D_i^* = \sqrt{\sum_{j=1}^{n}\sum_{k=1}^{l_j}(v_{ijk} - v_{jk}^*)^2}, \quad i = 1,..., m, \tag{29}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}\sum_{k=1}^{l_j}(v_{ijk} - v_{jk}^-)^2}, \quad i = 1,..., m. \tag{30}$$

Finally, the closeness coefficient $(\bar{C}_i)$ of alternative A_i to the ideal-solution can be calculated as

$$\bar{C}_i = \frac{D_i^-}{D_i^- + D_i^*}, \quad i = 1, 2, ..., m. \tag{31}$$

Obviously, $\bar{C}_i \in [0,1]$ and in addition, the higher the $\bar{C}_i$, the closer the alternative A_i to ideal solution and farther from negative-ideal solution. Therefore, according to the closeness coefficient, alternatives can be ranked so that the decision making group selects the most promising alternative among them.

4 A Numerical Example for Evaluating Vendors in a Supply Chain Using the Proposed Approach

4.1 Identifying Criteria and Sub-criteria

The vendor selection problem is a multi-criteria decision making, that is, there are several different and usually conflicting criteria that have to be taken into account for evaluating and selecting the most promising alternative. Dickson [17] identified 23 significant factors in vendor selection problems. Lehman and O'Shaughnessy [27] proposed 17 criteria for this purpose. Rao and Kiser [32] developed a list of 60 items categorized into six groups. Swift [35] considered 21 vendor-selection attributes for single sourcing. Mummalaneni *et al.* [31] proposed six attributes of on-time delivery, quality, price/cost targets, professionalism, responsiveness to customer needs, and long-term relationship with supplier as performance criteria of suppliers for Chinese purchasing managers. De Boer *et al.* [16] examined turnover, distance, cost level, and quality image as criteria for evaluating suppliers.

Tam and Tummala [36] introduced two strategic issues of cost and quality. Then they have broken down the cost issue into capital expenditure and operating expenditure, and similarly the quality issue into technical, operational and vendor criteria. In the next level they have divided these aforementioned criteria into more sub-criteria for vendor selection of telecommunication system. Shyur and Shih [34] proposed the following criteria: on-time delivery, product quality, price/cost, facility and technology, responsiveness to customer needs, professionalism of salesperson, and relationship with vendor. Wang *et al.* [37] applied four criteria of delivery reliability with sub-criteria of delivery performance, fill rate, order fulfillment lead time, and perfect order fulfillments; flexibility and responsiveness with sub-criteria of supply chain responsiveness, and production flexibility; cost with sub-criteria of total logistic management cost, value-added employee productivity, and warranty costs; and finally, assets with sub-criteria of cash-to-cash cycle time, inventory days of supply, and asset turns. Demirtas and Ustun [13] in their work included 14 criteria under 4 primary classes of benefits, costs, opportunities and risks. Chen *et al.* [5] used 5 criteria of profitability of supplier, relationship closeness, technological capability, conformance quality and conflict resolution in their work.

Incorporating too many criteria in the decision making process usually hinders the application of a mathematical method, specifically when using methods like AHP which demands high computational efforts. We believe that factors such as professionalism of salesperson, perfect order fulfillments, total logistic management cost, value-added employee productivity, cash-to-cash cycle time and capital expenditure don't play significant roles in selecting vendor(s). Instead, it is more effective to consider those factors which are more attractive for a typical decision-maker to select a vendor. Thus, in this section we consider 3 main criteria of cost, performance and quality with more sub-criteria as in Table 1.

Table 1: Criteria and sub-criteria for evaluating vendors in a supply chain

Criteria	Cost	Performance	Quality
Sub-criteria	Unit cost Warranty cost	Technological capability On-time delivery	Product quality Quality of relationship with supplier

These criteria and sub-criteria may not include all of the decision factors in vendor selection problem; Nevertheless, they are indeed meaningful and the most important measures and have been emphasized in many foremost papers, for example, Weber *et al.* [39], Mummalaneni *et al.* [31], and De Boer and van der Wegen [14].

4.2 Hierarchical Structure of Vendor Selection Problem

Assume that an automotive company is in a decision-making situation for purchasing one of the main items for their newly introduced automobile. A committee of three decision-makers $\{D_1,D_2,D_3\}$ want to select the most promising vendor for supplying the item. After a preliminary screening, four alternatives $\{A_1,A_2,A_3,A_4\}$ remain for further evaluations. The hierarchical structure of this problem is depicted in Figure 4.

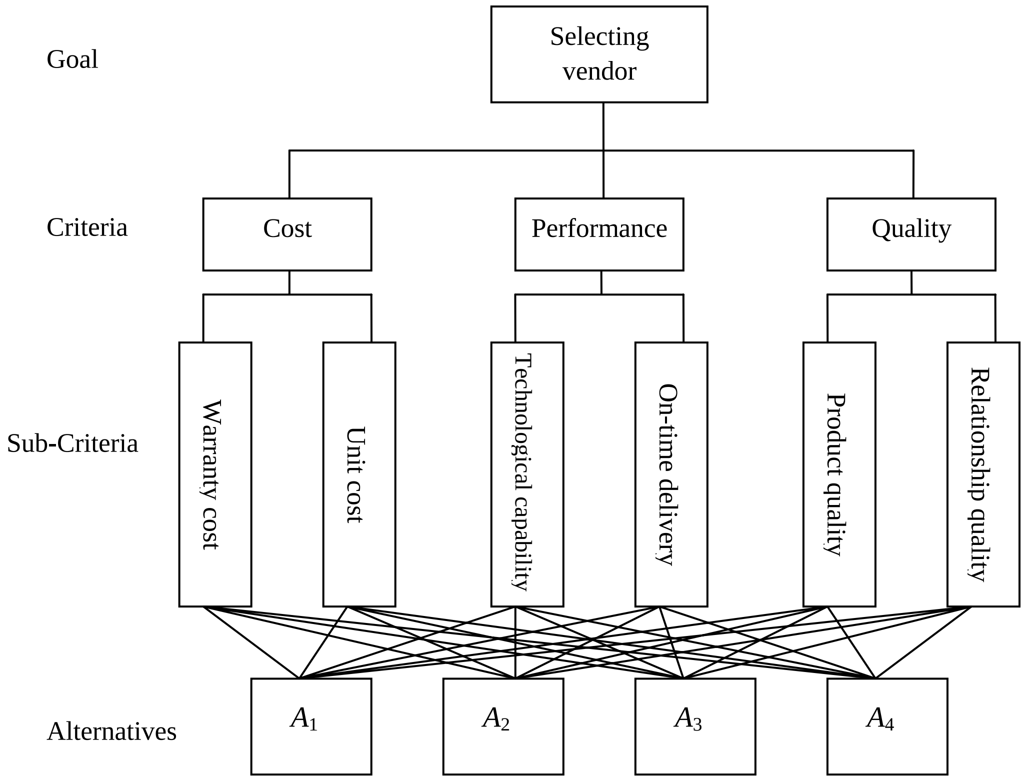

Figure 4: Hierarchical structure of vendor selection problem

Judgments of decision-makers for importance weight of criteria and sub-criteria are given in Table 2, and for ratings of alternatives are given in Tables 3, 4 and 5, respectively.

Table 2: Linguistic variables of importance weight of criteria and sub-criteria by decision-makers

	Decision-maker		
	D_1	D_2	D_3
Cost (C_1)	H	H	VH
Unit cost (S_{11})	H	VH	VH
Warranty cost (S_{12})	MH	M	H
Performance (C_2)	VH	VH	H
Technological capability (S_{21})	H	VH	H
Lead time (S_{22})	VH	VH	VH
Quality (C_3)	VH	H	VH
Product quality (S_{31})	VH	H	VH
Relationship quality (S_{32})	MH	H	H

Table 3: Linguistic variables of ratings of alternatives by decision-maker 1

Criteria	C1		C2		C3	
Sub-criteria	S_{11}	S_{12}	S_{21}	S_{22}	S_{31}	S_{32}
A_1	G	VG	G	MG	G	G
A_2	MG	G	VG	G	G	MG
A_3	F	G	G	VG	VG	F
A_4	F	F	VG	MG	MG	MG

Table 4: Linguistic variables of ratings of alternatives by decision-maker 2

Criteria	C1		C2		C3	
Sub-criteria	S_{11}	S_{12}	S_{21}	S_{22}	S_{31}	S_{32}
A_1	VG	VG	F	MG	MG	MG
A_2	G	G	G	G	G	F
A_3	MG	G	MG	VG	G	MP
A_4	F	MG	G	MG	G	MG

Table 5: Linguistic variables of ratings of alternatives by decision-maker 3

Criteria	C1		C2		C3	
Sub-criteria	S_{11}	S_{12}	S_{21}	S_{22}	S_{31}	S_{32}
A_1	G	VG	G	G	G	VG
A_2	VG	G	G	VG	G	MG
A_3	G	VG	MG	VG	VG	MP
A_4	MG	G	G	F	G	MG

Table 6: The fuzzy decision matrix for vendor selection problem

Criteria (weight)	C_1 (0.7, 0.83, 0.87, 1)		C_2 (0.7, 0.87, 0.93, 1)		C_3 (0.7, 0.87, 0.93, 1)	
Sub-criteria (weight)	S_{11} (0.7,0.87,0.93,1)	S_{12} (0.4,0.63,0.67,0.9)	S_{21} (0.7,0.83,0.87,1)	S_{22} (0.8,0.9,1,1)	S_{31} (0.7,0.87,0.93,1)	S_{32} (0.5,0.73,0.77,0.9)
A_1	(7,8.33,8.67,10)	(8, 9, 10, 10)	(4, 7, 7, 9)	(5,6.67, 7.33,9)	(5, 7.33, 7.67, 9)	(5, 7.67, 8.33, 10)
A_2	(5,7.67,8.33,10)	(7, 8, 8, 9)	(7, 8.33,8.67,10)	(7,8.33,8.67,10)	(7, 8, 8, 9)	(4, 5.67, 6.33, 8)
A_3	(4,6.33,6.67,9)	(7, 8.33, 8.67, 10)	(5, 6.67, 7.33, 9)	(8, 9, 10, 10)	(7,8.67,9.33, 10)	(2, 3.67, 4.33, 6)
A_4	(4,5.33,5.67,8)	(4, 6.33, 6.67, 9)	(7,8.33,8.67,10)	(4,5.67, 6.33, 8)	(5, 7.33, 7.67, 9)	(5, 6, 7, 8)

Table 7: The normalized fuzzy decision matrix for vendor selection problem

Criteria (weight)	C_1 (0.7, 0.83, 0.87, 1)		C_2 (0.7, 0.87, 0.93, 1)		C_3 (0.7, 0.87, 0.93, 1)	
Sub-criteria (weight)	S_{11} (0.7,0.87,0.93,1)	S_{12} (0.4,0.63,0.67,0.9)	S_{21} (0.7,0.83,0.87,1)	S_{22} (0.8,0.9,1,1)	S_{31} (0.7,0.87,0.93,1)	S_{32} (0.5,0.73,0.77,0.9)
A_1	(0.7,0.83,0.87,1)	(0.8,0.9,1,1)	(0.4,0.7,0.7,0.9)	(0.5,0.67,0.73,0.9)	(0.5,0.73,0.77,0.9)	(0.5,0.77,0.83., 1)
A_2	(0.5,0.77,0.83,1)	(0.7,0.8,0. 8,0.9)	(0.7,0.83,0.87,1)	(0.7,0.83,0.87,1)	(0.7,0.8,0.8,0.9)	(0.4,0.57,0.63,0.8)
A_3	(0.4,0.63,0.67,0.9)	(0.7,0.83,0.87,1)	(0.5,0.67,0.73,0.9)	(0.8,0.9,1,1)	(0.7,0.87,0.93,1)	(0.2,0.37,0.43,0.6)
A_4	(0.4,0.53,0.57,0.8)	(0.4,0.63,0.67,0.9)	(0.7,0.83,0.87,1)	(0.4,0.57,0.63,0.8)	(0.5,0.73,0.77,0.9)	(0.5,0.6,0.7, 0.8)

Table 8: The weighted normalized decision matrix for vendor selection problem

Criteria	C_1		C_2		C_3	
Sub-criteria	S_{11}	S_{12}	S_{21}	S_{22}	S_{31}	S_{32}
A_1	0.64	0.52	0.51	0.58	0.57	0.51
A_2	0.59	0.44	0.64	0.70	0.62	0.39
A_3	0.49	0.47	0.53	0.77	0.69	0.26
A_4	0.43	0.36	0.64	0.49	0.57	0.42

Table 9: Final evaluation of alternatives

	(D_i^*)	(D_i^-)	$\bar{C}_i = \frac{D_i^-}{D_i^- + D_i^*}$	Rank
A_1	0.259	0.375	0.591	2
A_2	0.182	0.335	0.648	1
A_3	0.316	0.330	0.511	3
A_4	0.413	0.206	0.333	4

The fuzzy decision matrix, normalized fuzzy decision matrix and weighted normalized decision matrix of this problem are given in Tables 6, 7 and 8, respectively.

The positive ideal solution (PIS, A^*) and negative-ideal solution (NIS, A^-) are as follows

$$A^* = (0.64, 0.52, 0.64, 0.77, 0.69, 0.51),\ A^- = (0.43, 0.36, 0.51, 0.49, 0.57, 0.26).$$

Distance of each alternative from ideal solution (D_i^*), and negative-ideal solution (D_i^-), and closeness coefficient $(\bar{C}_i)$ are calculated as in Table 9.

According to Table 9, supplier A_2 with $\bar{C}_2 = 0.648$ is the superior supplier among suppliers A_1, A_2, A_3 and A_4, and therefore will be recommended to select for providing that specific item for the company.

5 Conclusions

Vendor selection is a very important and critical multi-criteria decision making problem in supply chains such that making an improper decision has adverse effects on the entire supply chain. This fact has attracted attentions of many researchers to find better and more realistic approaches to dealing with this problem. This paper presented a new fuzzy multiple criteria group decision making (FMCGDM) approach for vendor (supplier) selection problem. The proposed approach is based on TOPSIS method under fuzzy environment to account for vagueness and uncertainty of the real-world situations. In the proposed approach, a four-level hierarchy problem consisting of goal, criteria, sub-criteria and alternatives was proposed, and to construct the weighted normalized decision matrix of the TOPSIS method, canonical representation of multiplication operation on three trapezoidal fuzzy numbers was used. Finally, an illustrative example was conducted to show applicability of our approach in ranking and selecting an appropriate vendor(s) by a group of decision-makers.

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References

[1] Aissaoui, N., M. Haouari, and E. Hassini, Supplier selection and order lot sizing modeling: a review, *Computers & Operations Research*, vol.34, pp.3516-3540, 2007.
[2] Almeida, A.T., Multicriteria decision model for outsourcing contracts selection based on utility function and ELECTRE method, *Computers & Operations Research*, vol.34, pp.3569-3574, 2007.
[3] Bender, P.S., R.W. Brown, M.H. Isaac, and J.F. Shapiro, Improving purchasing productivity at IBM with a normative decision support system, *Interfaces*, vol.15, no.3, pp.106-115, 1985.
[4] Buffa, F.P., and W.M. Jackson, A goal programming model for purchase planning, *Journal of Purchasing and Materials Management*, vol.19, no.3, pp.27-34, 1983.
[5] Chen, C.T., C.T. Lin, and S.F. Huang, A fuzzy approach for supplier evaluation and selection in supply chain management, *Int. J. Production Economics*, vol.102, pp.289-301, 2006.
[6] Chen, S.J., and C.L. Hwang, *Fuzzy Multiple Attribute Decision Making Methods and Applications*, Springer, Berlin, 1992.
[7] Chen, M.F., and G.H. Tzeng, Combining grey relation and TOPSIS concepts for selecting an expatriate host country, *Mathematical and Computer Modelling*, vol.40, no.13, pp.1473-1490, 2004.
[8] Chen, C.T., A fuzzy approach to select the location of the distribution center, *Fuzzy Sets and Systems*, vol.118, no.1, pp.65-73, 2001.
[9] Chen, C.T., Extensions of the TOPSIS for group decision-making under fuzzy environment, *Fuzzy Sets and Systems*, vol.114, pp.1-9, 2000.

[10] Chou, C.C., The canonical representation of multiplication operation on triangular fuzzy numbers, *International Journal of Computers and Mathematics with Applications*, vol.45, pp.1601-1610, 2003.

[11] Chou, C.C., A fuzzy MCDM method for solving marine transshipment container port selection problems, *Applied Mathematics and Computation*, vol.186, pp. 435-444, 2007.

[12] Chou, S.Y., and Y.H. Chang, A decision support system for supplier selection based on a strategy-aligned fuzzy SMART approach, *Expert Systems with Applications*, vol.34, pp.2241-2253, 2008.

[13] Demirtas, E.A., and O. Ustun, Analytic network process and multi-period goal programming integration in purchasing decisions, *Computers & Industrial Engineering*, vol.56, pp.677-690, 2009.

[14] De Boer, L., and L. van der Wegen, Practice and promise of formal supplier selection: a study of four empirical cases, *Journal of Purchasing and Supply Management*, vol.9, pp.109-118, 2003.

[15] De Boer, L., E. Labro, and P. Morlacchi, A review of methods supporting supplier selection, *European Journal of Purchasing and Supply Management*, vol.7, pp.75-89, 2001.

[16] De Boer, L., L. van der Wegen, and J. Telgen, Outranking methods in support of supplier selection, *European Journal of Purchasing and Supply Management*, vol.4, pp.109-118, 1998.

[17] Dickson, G.W., An analysis of vendor selection systems and decisions, *Journal of Purchasing*, vol.2, pp.5-17, 1966.

[18] Farzipoor Saen, R., Suppliers selection in the presence of both cardinal and ordinal data, *European Journal of Operational Research*, vol.183, pp.741-747, 2007.

[19] Gao, Z., and L. Tang, A multi-objective model for purchasing of bulk raw materials of a large-scale integrated steel plant, *International Journal of Production Economics*, vol.83, pp.325-334, 2003.

[20] Ghodsypour, S.H., and C. O'Brien, A decision support system for supplier selection using an integrated analytic hierarchy process and linear programming, *International Journal of Production Economics*, vol.56-57, pp.199-212, 1998.

[21] Hsu, H.M., and C.T. Chen, Aggregation of fuzzy opinions under group decision making, *Fuzzy Sets and System*, vol.79, no.3, pp.279-285, 1996.

[22] Hsu, H.M., and C.T. Chen, Fuzzy credibility relation method for multiple criteria decision-making problems, *Information Sciences*, vol.96, pp.79-91, 1997.

[23] Handfield, R., S.V. Walton, R. Sroufe, and S.A. Melnyk, Applying environmental criteria to supplier assessment: a study in the application of the analytical hierarchy process, *European Journal of Operational Research*, vol.141, pp.70-87, 2002.

[24] Hwang, C.L., and K. Yoon, *Multiple Attribute Decision Making*, Springer-Verlag, Berlin, 1981.

[25] Kacprzyk, J., Group decision making with a fuzzy linguistic majority, *Fuzzy Sets and Systems*, vol.18, no.2, pp.105-108, 1986.

[26] Kumar, M., P. Vrat, and R. Shankar, A fuzzy programming approach for vendor selection problem in a supply chain, *International Journal of Production Economics*, vol.101, no.2, pp.273-285, 2006.

[27] Lehman, D.R., and J. O'Shaughnessy, Difference in attribute importance for different industrial products, *Journal of Marketing*, vol.38, pp.36-42, 1974.

[28] Li, G.D., D. Yamaguchi, and M. Nagai, A grey-based decision-making approach to the supplier selection problem, *Mathematical and Computer Modelling*, vol.46, pp.573-581, 2007.

[29] Liu, F.H.F., and H.L. Hai, The voting analytic hierarchy process method for selecting supplier, *Int. J. Production Economics*, vol.97, pp.308-317, 2005.

[30] Moore, D.L., and H.E. Fearon, Computer-assisted decision-making in purchasing, *Journal of Purchasing*, vol.9, no.4, pp.5-25, 1972.

[31] Mummalaneni, V., K.M. Dubas, and C. Chao, Chinese purchasing managers' preferences and trade-offs in supplier selection and performance evaluation, *Industrial Marketing Management*, vol.25, pp.115-124, 1996.

[32] Rao, C.P., and G.E. Kiser, Educational buyers' perceptions of vendor attributes, *Journal of Purchasing and Materials Management*, vol.16, pp.25-30, 1980.

[33] Sharma, D., W.C. Benton, and R. Srivastava, Competitive strategy and purchasing decisions, *Proceedings of the 1989 Annual Conference of the Decision Sciences Institute*, pp.1088-1090, 1989.

[34] Shyur, H.J., and H.S. Shih, A hybrid MCDM model for strategic vendor selection, *Mathematical and Computer Modelling*, vol.44, pp.749-761, 2006.

[35] Swift, C.O., Preferences for single sourcing and supplier selection criteria, *Journal of Business Research*, vol.32, pp.105-111, 1995.

[36] Tam, M.C.Y., and V.M.R. Tummala, An application of the AHP in vendor selection of a telecommunications system, *Omega*, vol.29, pp.171-182, 2001.

[37] Wang, G., S.H. Huang, and J.P. Dismukes, Product-driven supply chain selection using integrated multi-criteria decision-making methodology, *International Journal of Production Economics*, vol.91, pp.1-15, 2004.

[38] Weber, C.A., J.R. Current, and A. Desai, An optimization approach to determining the number of vendors to employ, *Supply Chain Management: An International Journal*, vol.2, no.5, pp.90-98, 2000.

[39] Weber, C.A., J.R. Current, and W.C. Benton, Vendor selection criteria and methods, *European Journal of Operational Research*, vol.50, no.1, pp.2-18, 1991.

[40] Yahya, S., and B. Kingsman, Vendor rating for an entrepreneur development programme: a case study using the analytic hierarchy process method, *Journal of the Operational Research Society*, vol.50, pp.916-930, 1999.

[41] Zadeh, L.A., The concept of a linguistic variable and its application to approximate reasoning, Part 1, 2, and Part 3, *Information Sciences*, vol.8, no.3, pp.199–249(I), vol.8, no.4, pp.301–357(II), vol.9, no.1, pp.43-58(III), 1975.