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Supplier Selection Strategies on Fuzzy Decision Space

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Abstract

Supplier selection is a major strategy for manufacture to run the production process smoothly. Supplier categorization, selection and performance evaluation are decisions of strategic importance to companies. Global competition, mass customization, high customer expectations and harsh economic conditions are forcing companies to rely on external suppliers to contribute a larger portion of parts, materials, and assemblies to finished products and to manage a growing number of processes and functions that were once controlled internally. Thus supplier performance evaluation is very important to choose the right supplier for the right product. In this paper a fuzzy supplier selection algorithm (FSSA) is implemented to rank the technically efficient vendors according to both predetermined performance criteria and additional product-related performance criteria. Investigation of the properties of the best supplier alternative by ranking the fuzzy indices allow to develop an algorithm which is based on calculating fuzzy suitability indices for the efficient supplier alternatives and validity is illustrated through an example problem.

Keywords: *Fuzzy Logic Performance Evaluation, Supplier Selection, Defuzzification.*

1 Introduction

In real world, the company often makes use of supplier selection on fuzzy decision space to promote their commodities. The selection of supplier of enterprise is an important issue to enterprise itself. The main role of purchasing in a business enterprise is to support the business and production activities by providing continuous material and service flow. Because a typical manufacturing company spends 60% of its sales on purchasing materials, goods and services from external suppliers, the quality, cost and other aspects of the end-product is influenced by suppliers' performance. Consequently the results of obtaining a bad decision about purchasing operations are resulting more severe with the increasing dependency of the organizations on suppliers.
Thus, purchasing and manufacturing strategies must be compatible with each other and should support the competitive strategies at all levels of the organization. This means the operation / production department, marketing department, and finance department in an enterprise jointly to determine these decisions. Therefore the decision-making involves selecting the right supplier, marketing, inventory and financing issues. So, an investigation of this integrated model is very important and valuable to the enterprise. However, the most important thing is that purchasing concepts and functions must be put into operation and set within a realistic system. To ensure this the decision process of purchasing must be modeled and structured in a realistic way. In addition, today's purchasing literature; various works have been compiled about the modeling of purchasing decisions and especially supplier selection and facilitating decision making. For the last 10 years, use of artificial intelligence (AI) techniques in increasing. Therefore, it makes economic sense for enterpriser or decision maker to use fuzzy logic, one of the AI techniques, has a limited use in this research.
This paper tries to adopt fuzzy arithmetic approach for modeling the supplier selection of the organization. Here, initially, the literature about purchasing and supplier selection topic is presented and later, the fuzzy logic method adopted in modeling supplier selection process will be explained. Finally a numerical example will be given in order to illustrate the decision procedure and managerial insights are drawn.

2 Literature Review on Supplier Selection

An early study of supplier selection in production process is discussed in three categories by [37]

- i) Supplier Selection Criteria
- ii) Purchasing environments
- iii) Appropriate decision techniques.

The approach helps the decision maker to find different method to use in multiple areas according to different situations.

From this categorization, the supplier selection process can be separated into four steps [9]:

1. Finding out what exactly we want to achieve with the supplier selection.
2. Determining the Criteria
3. Pre-evaluation of the suitable suppliers
4. Final choice.

Most of the decision models in the literature are developed to be applied in the final choice of the purchasing process. Maximum selection models are characterized as 'single-deal' or 'package' models and most of the decision methods focused on solving these models [10].
On the other hand, one of the methods used in supplier selection is total cost of ownership (TCO) models. TCO-based models try to take costs that will be received during the life cycle of the purchased product into account. Three separations can be made about these costs.

1. Costs before the process
2. Costs during the process
3. Costs after the process [12]

Another decision method used for supplier selection is mathematical programming (MP) models. But Timmerman proposed the Cost-rate method' for companies that have computer accounting systems [32]. Above all, [19] and [30] suggested a model that combines the TCO approach and scoring systems for a special costing case. But MP models are more objective than the scoring methods but these models take only quantitative criteria into account.
Statistical models are another method hat deals with the stochastic uncertainty in supplier selection. [26] discussed a decision support system for the situations when only order delivery time is uncertain [31] proposed a statistical simulation model that presents a solution for uncertain demand situations.
[22], [7], [28] and [27] introduce models that assumed predetermined levels of quality, service and delivery constraints. [37] combine the MP and the DEA methods to provide buyers with a tool for negotiations with suppliers that were not selected right away as well as to evaluate different numbers of suppliers to use.
As a matter of fact another solution to the supplier selection problem is AI-based models. Neural networks and expert systems are examples of AI-based methods. [1] propose a decision support system based on neural networks while [33] developed an expert system that is able to support the decision maker in the supplier choice phase. In addition to the basis method, the supplier with the highest overall rating can be selected as the suitable supplier, there are several adaptations. [40] and [32] refer to this model in their purchasing books. In the literature there are some methods proposing the use of an analytical hierarchy process (AHP) i.e. [20], [21], [2], an analytical network process (ANP) i.e. [29],

and statistical methods i.e. [38], [18], [24] together with linear weighting models in order to compensate for some disadvantages of the weighting model.
Finally, some authors suggest using fuzzy set theory to model the uncertainty of supplier selection [16] and [14] have studied by applying these methods.

3 Methodology

Before shifting to the supplier selection approach some methods utilized in this approach are briefly introduced in this section.

3.1. Fuzzy Set Theory

Fuzzy set theory was initially introduced by [39] to deal with problems involving the absence of sharply defined criteria. Subsequently, the improvement and application of fuzzy numbers was studied by [11].

3.2.1. Trapezoidal Fuzzy Numbers

In a universe of discourse of X, a fuzzy subset A of X is characterized by a membership function f_A, which maps each element x in X to a real number in the interval [0, 1]. The function value represents the grade of membership of x in A.
A fuzzy number A [7, 8] in < (real line) is a trapezoidal fuzzy number if its membership function $f_A : R \to [0,1]$ is

$$f_A(x) = \begin{cases} (x-c)/(a/c), & c \le x \le a \\ 1, & a \le x \le b \\ (x-d)/(b-d), & b \le x \le d \\ 0, & otherwise \end{cases}$$

With $-\infty < c < a < b < d < \infty$ the trapezoidal fuzzy number A, shown in figure 1, can be represented by (c, a, b, d)
The strongest grade of membership is for the trapezoidal fuzzy number A in the interval [a, b], i.e. $f_A(x) = 1; x \in [a,b]$; this is the highest possible value of evaluation data. In addition, c and d are the lower and upper bounds of the available area for the evaluation data. They are used to reflect the fuzziness of the evaluation data. The narrower the interval [c, a] and [b, d], the lower the Fuzziness of the evaluation data.
By the extension principle, the extended algebraic operations of any two trapezoidal fuzzy numbers A = (c, a, b, d); and B = (g, e, f, h) can be expressed as:

Addition $\oplus$:

$$A \oplus B = (c+g, a+e, b+f, d+h)$$

Multiplication $\otimes$:

$$K \otimes A = K \otimes (c, a, b, d)$$
$$= (Kc, Ka, Kb, Kd) \quad K \geq 0, K \in R$$

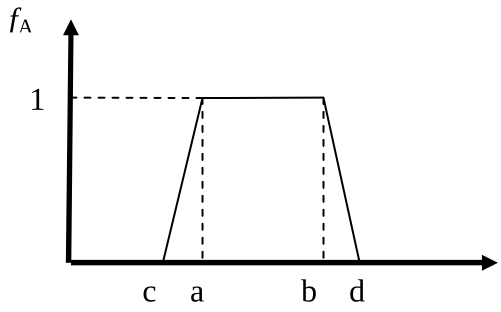

Figure 1. A sample of trapezoidal fuzzy number.

3.2.2. Fuzzy Logic Operators

When fuzzy sets are used in the decision making problem, the idea of trade-offs between conflicting criteria are realized with the help of fuzzy logic operators $(f.l.o.)$ [41] and [34] when compensation is allowed. The first one introduced by [39] are min, max and 1- μ (μ is the membership degree to a given fuzzy set). However, the degree compensation through which human aggregate criteria is not expressed by these operators. There exists some $(f.l.o.)$ that more accurately represent human decision making. Weighted mean and Maxmin [41] and [34] are the examples of averaging operators, Weighted mean operator is a convex composition of several fuzzy sets with coefficients that express the 'percentage' of a given set in the aggregating set. The formulation of the weighted mean operator is shown below:

$$\mu_i = (x) = \sum_{j=1}^{m} c_j \mu_{ij}(x),$$

$$\sum_{j=1}^{m} c_j = 1, i = 1,2,...,n$$

3.2.3. Linguistic Variables

A Linguistic variable is a variable whose values are expressed in terms of words or sentences instead of numbers. The concept of linguistic variable is very useful in situations where decision problems are too complex or too ill-defined to be described properly using conventional quantitative expressions. For example, the performance ratings of alternatives on qualitative attributes could be expressed using linguistic variable such as very poor, poor, fair, good, very good, excellent etc. Such linguistic values can be represented using positive triangular fuzzy numbers. For example 'poor' and 'very good' can be represented by the positive trapezoidal fuzzy numbers (0.2, 0.3, 0.4, 0.5) and (0.6, 0.8, 0.9, 1.0), respectively.

3.2.4. Ranking Method

In order to elicit the magnitude of the numbers in a fuzzy number group a ranking method should be introduced. The literature review reveals that magnitudes of fuzzy set ranking methods exist i.e. [3], [8], [5], [15], [17], [6], [13], [23] and [35]. One of the most common methods for ranking is Chen's method. [8] Chen's Ranking method is chosen for this study due to its easy usage and efficient results.

4 Methods and Procedure of Supplier Performance Evaluation

The supplier selection approach is based on the method of collecting the subjective evaluations of single or multiple decision makers (purchasing experts) in order to reach a final choice. In the method, n decision makers evaluate the performance of the m supplies in k criteria and rate the importance of the k criteria in linguistic expression. Furthermore, linguistic expressions are converted into fuzzy numbers, processed in provided formulas and finally the performance ranking of the suppliers are obtained.
The execution steps of the method are

I) Determination of the importance degree of the performance criteria in linguistic expressions.
II) Determination of the performance of suppliers in each criterion in linguistic expressions.
III) Fuzzification of the criteria's importance degrees and performance evaluations.
IV) Aggregation of the criteria importance weights with fuzzy mean operator.
V) Aggregation of the performance evaluations for each criterion with fuzzy mean operator.
VI) Aggregation of the importance weights and performance evaluations with fuzzy weighted mean operator and obtaining fuzzy preference index.
VII) Defuzzification and ranking of the required fuzzy preference index for each supplier alternative.

Steps I-II Determining the Importance Degrees and Performances

Throughout the method, we assume that there are n decision makers (purchasing experts) who assess the importance weights of k criteria and the performances of m supplier alternatives. The decision makers use a set of weights, W = (VL, L, M, H, VH) to appraise W_{ti} weights of k criteria. Here, VL indicates very low, L low, M middle, H high and VH very high linguistic expressions for importance weights of criteria. The membership functions and system parameters of these fuzzy linguistic variables are:

VL: (0, 0, 0, 0. 2)

$$\mu_{VL}(x) = \begin{cases} 1-5x, 0 \le x \le 0.2 \\ 0, \quad otherwise \end{cases}$$

L (0, 0.2, 0.2, 0.4)

$$\mu_{L}(x) = \begin{cases} 5x, \quad 0 \le x \le 0.2 \\ 2-5x, 0.2 \le x \le 0.4 \\ 0, \quad otherwise \end{cases}$$

M: (0.3., 0.5, 0.5, 0.7)

$$\mu_{M}(x) = \begin{cases} 5x-3/2, 0.3 \le x \le 0.5 \\ 7/2-5x, 0.5 \le x \le 0.7 \\ 0, \quad otherwise \end{cases}$$

H: (0.5, 0.8, 0.8, 1)

$$\mu_{H}(x) = \begin{cases} \frac{10x}{3} - \frac{5}{3}, 0.5 \le x \le 0.8 \\ 5-5x, \quad 0.8 \le x \le 1 \\ 0, \quad otherwise \end{cases}$$

VH: (0.8, 1, 1, 1)

$$\mu_{VH}(x) = \begin{cases} 5x-4, \quad 0.8 \le x \le 1 \\ 0 \quad otherwise \end{cases}$$

Wt_j = Linguistic value given by j decision maker for t criterion.
$Wt_j = c_{tj}, a_{t_j}, b_{t_j}, d_{t_j}$
t = 1, 2, ..., K
j = 1, 2, ..., n

This scale is chosen because of its best fit with the previous usage in recent articles [17]. For determining supplier performances, n decision makers assess the A_{it} subjective performance values of m supplier according to their previous experience and opinions. Here this paper uses the 9 scale of [17] for linguistic values.
The variable set for performance evaluation is A = (VP, VP & P, P P & M, M, M&G, G, G & VG, VG). Here VP indicates very poor, VP & P between very poor and poor, P poor, P&M between poor and middle, M middle, M&G between

middle and good, G good, G&VG between good and very good, and VG very good.
The membership functions and system parameters of these linguistic variables are

VP: (0, 0, 0, 0, 0.2)

$$\mu_{VP}(x)=\begin{cases}1-5x, 0\le x\le 0.2\\ 0, \quad otherwise\end{cases}$$

VP & P: (0, 0, 0, 0.2, 0.4)

$$\mu_{VP\&P}(x)=\begin{cases}1, \quad 0\le x\le 0.2\\ 2-5x, 0.2\le x\le 0.4\\ 0, \quad otherwise\end{cases}$$

P: (0, 0.2, 0.2, 0.4)

$$\mu_{P}(x)=\begin{cases}5x, \quad 0\le x\le 0.2\\ 2-5x, 0.2\le x\le 0.4\\ 0, \quad otherwise\end{cases}$$

P & M: (0, 0.2, 0.5, 0.7)

$$\mu_{P\&M}(x)=\begin{cases}5x, \quad 0\le x\le 0.2\\ 1, \quad 0.2\le x\le 0.5\\ 7/2-5x, 0.5\le x\le 0.7\\ 0, \quad othrewise\end{cases}$$

M: (0.3, 0.5, 0.5, 0.7)

$$\mu_{M}(x)=\begin{cases}5x-3/2, 0.3\le x\le 0.5\\ 7/2-5x, 0.5\le x\le 0.7\\ 0, \quad otherwise\end{cases}$$

M & G: (0.3, 0.5, 0.8, 1)

$$\mu_{M\&G}(x)=\begin{cases}5x-3/2, 0.3\le x\le 0.5\\ 1, \quad 0.5\le x\le 0.8\\ 5-5x, \quad 0.8\le x\le 1\\ 0, \quad othrewise\end{cases}$$

G: (0.6, 0.8, 0.8,1)

$$\mu_G(x) = \begin{cases} 5x-3, 0.6 \le x \le 0.8 \\ 5-5x, \quad 0.8 \le x \le 1 \\ 0, \quad otherwise \end{cases}$$

G & VG: (0.6, 0.8, 1, 1)

$$\mu_{G\&VG}(x) = \begin{cases} 5x-3, 0.6 \le x \le 0.8 \\ 1, \quad 0.8 \le x \le 1 \\ 0, \quad otherwise \end{cases}$$

VG: (0.8, 1, 1, 1)

$$\mu_{VG}(x) = \begin{cases} 5x-4, 0.8 \le x \le 1 \\ 0 \quad otherwise \end{cases}$$

A_{itj} = the linguistic value, given by j decision maker, of i supplier for t criterion.

$$A_{itj} = (q_{itj}, o_{itj}, p_{itj}, r_{itj})$$

$$\begin{cases} i = 1,2,...m \\ t = 1,2,...k \\ j = 1,2,...n \end{cases}$$

Step III Fuzzification

The given performance values and criteria weights are converted into trapezoidal fuzzy numbers according to the determined evaluation scale.

Step IV-V Aggregation of Importance Weights and Performance Evaluations

Performance values and criteria weights assessed by the decision makers are aggregated separately for each c_t (t = 1, 2 ..., k) criterion by the fuzzy mean operator and thereby, for each criterion, W_t fuzzy weight and A_{it} fuzzy performance values are obtained. The formulations and parameter of the calculations are:

$$W_t = \left(\frac{1}{n}\right) \otimes (W_{t1} \otimes W_{t2} \otimes ... \otimes W_{tn})$$

t = 1, 2, ... k

$$W_t = (c_t, a_t, b_t, d_t)$$

$$c_t = \sum_{j=1}^{n} \frac{c_{tj}}{n}$$

$$a_t = \sum_{j=1}^{n} \frac{a_{tj}}{n}$$

$$b_t = \sum_{j=1}^{n} \frac{b_{tj}}{n}$$

$$d_t = \sum_{j=1}^{n} \frac{d_{tj}}{n}$$

$$A_t = \left(\frac{1}{n}\right) \otimes (A_{it1} \otimes A_{it2} \otimes \ldots \otimes A_{itn})$$

i = 1, 2, ..., m
t = 1, 2, ..., k
$A_{it} = (q_{it}, o_{it}, p_{it}, r_{it})$

$$q_{it} = \sum_{j=1}^{n} \frac{q_{itj}}{n}$$

$$o_{it} = \sum_{j=1}^{n} \frac{o_{itj}}{n}$$

$$p_{it} = \sum_{j=1}^{n} \frac{p_{itj}}{n}$$

$$r_{it} = \sum_{j=1}^{n} \frac{r_{itj}}{n}$$

i = 1, 2, ... m
t = 1, 2, ..., k

Step-VI. Obtaining Fuzzy Preference Index

After steps IV & V, importance weights and performance values are aggregated together with fuzzy mean operator in order to obtain a fuzzy preference index. These operations are defined as:

$$F_i = \left(\frac{1}{k}\right) \otimes [(A_{i1} \otimes W_1) \otimes (A_{i2} \otimes W_2) \otimes \ldots\ldots \otimes (A_{in} \otimes W_n)]$$

According to the extension principle of [39], F_i is fuzzy number with membership function.

$$\mu_{F_i}(x) = \begin{cases} -H_{i1} + \left[H_{i1}^2 + (x - y_i)/T_{i1}\right]^{1/2}, & Y_i \le x \le Q_i \\ 1, & Q_i \le x \le R_i \\ H_{i2} + \left[H_{i2}^2 + (x - z_i)/U_{i1}\right]^{1/2}, & R_i \le x \le Z_i \\ 0, & otherwise \end{cases}$$

i = 1, 2 .... m

$F_i = (Y_i, O_i, R_i, Z_i, H_{i1}, H_{i2}, U_{i1})$
$i = 1, 2, ..., m$

Here T_{i1}, T_{i2}, U_{i1}, U_{i2}, Y_i, O_i, R_i, Z_i, H_{i1} and H_{i2} values are calculated as:

$$T_{i1} = \sum_{i=1}^{k} \frac{(o_{it} - q_{it})(a_t - c_t)}{k}$$

$$T_{i2} = \sum_{i=1}^{k} \frac{[q_{it}(a_t - c_t) + c_t(o_{it} - q_{it})]}{k}$$

$$U_{i1} = \sum_{i=1}^{k} \frac{(r_{it} - p_{it})(d_t - b_t)}{k}$$

$$U_{i2} = \sum_{i=1}^{k} \frac{[d_t(p_{it} - r_{it}) + r_{it}(b_i - d_i)]}{k}$$

$$Y_i = \sum_{i=1}^{k} \frac{q_{it}.c_t}{k}$$

$$o_i = \sum_{i=1}^{k} \frac{o_{it}.a_t}{k}$$

$$R_i = \sum_{i=1}^{k} \frac{p_{it}.b_t}{k}$$

$$Z_i = \sum_{i=1}^{k} \frac{r_{it}.d_t}{k}$$

$$H_{i1} = \frac{T_{i2}}{(2T_{i1})}$$

$$H_{i2} = \frac{U_{i2}}{(2U_{i1})}$$

It can be examined that F_i fuzzy preference index is not actually a trapezoidal fuzzy number. In order to obtain this, the approximation below can be written:

$$F \approx (Y_i, O_i, R_i, Z_i)$$

Step – VII. Defuzzification and Ranking of the Preference Index

Defuzzification of trapezoidal fuzzy numbers of F_i index that is calculated for each supplier alternative and the ordering or ranking of these crisp numbers is the last operations of the supplier selection method.

[8] proposed a method that defuzzifies and ranks the numbers in a fuzzy set. This method is chosen as the most appropriate method due to its general, easy use and consistency in results [25]. This method is an approach for ranking a fuzzy number set with a way that combines minimizing set and maximizing set

approaches. The membership functions of maximizing set M and minimizing set G for a trapezoidal fuzzy number $A_i = (c_i, a_i, b_i, d_i)$ are:

$$\mu_M(x) = \begin{cases} \left[\dfrac{x - x_{\min}}{x_{\max} - x_{\min}}\right]^k, & x_{\min} \le x \le x_{\max} \\ 0, & otherwise \end{cases}$$

$$\mu_G(x) = \begin{cases} \left[\dfrac{x - x_{\max}}{x_{\min} - x_{\max}}\right]^k, & x_{\min} \le x \le x_{\max} \\ 0, & otherwise \end{cases}$$

$x_{\max} = \sup S$
$x_{\min} = \inf S$

$$S = \bigcup_{i=1}^{n} S_i, \; S_i = \text{des } A_i \; S_i = \text{des } A_i$$

The linear case is given by k = 1 (risk neutral), while k > 1 represents risk-prone (convex) membership functions, and 0 < k < 1 represents risk-averse (concave) membership functions. In here, the value of k is assigned to be 1. When k = 1 the ranking value of A_i is calculated using the following expression:

$$U_T(i) = \frac{1}{2} \times \left[\frac{(d_i - x_{\min})}{((x_{\max} - x_{\min}) - (b_i - d_i))} + \frac{1 - (x_{\max} - c_i)}{((x_{\max} - x_{\min}) - (a_i - c_i))}\right],$$
i = 1, 2, ... n

Numerical Example

Suppose that in a manufacturing company, five purchaser experts (DM) are identified to evaluate 20 supplier alternatives (T_i, i =1, 2... 20) in four performance criteria. These are delivery, quality, flexibility and service.

The decision makers utilize a linguistic set of weights that are stated in step I, to identify the importance of each criterion. The weights assigned to the seven criteria by the five decision makers are given Table-1.

We assume that the decision makers use the linguistic variable set given in step II, to assess the suitability of the supplier alternative under each of the subjective criteria. The linguistic ratings are presented (illustrated) in Tables 2-5.

Table-1
The importance weights of the decision criteria

Decision Criteria	**DM_1**	**DM_2**	**DM_3**	**DM_4**	**DM_5**
Delivery	VH	VH	VH	H	H

Quality	VH	H	M	H	M
Flexibility	H	VH	H	VH	VH
Service	H	H	M	L	VL

The aggregate weights for each criterion are calculated by grouping the linguistic assessments of the five decision makers. The aggregate weights calculated by employing equation in step IV are given below:

$W_1 = (0.68, 0.92, 0.92, 1)$ $W_2 = (0.48, 0.72, 0.72, 0.88)$
$W_3 = (0.68, 0.92, 0.92, 1)$ $W_4 = (0.26, 0.46, 0.46, 0.66)$

The fuzzy performance values for all supplier alternatives in each criterion are computed by using equation in Step V. The results are shown in Tables 6-9
Fuzzy suitability index values for the supplier alternatives are obtained by averaging the products of weights and linguistic ratings over all the criteria via a weighted mean operator. The results are illustrated in Table 10.
The equation in step VII is used to determine the ranking values of the supplier alternatives. The ranking of the suppliers are given in Table 11. From the table, T_4 appears to be the best supplier alternative as a result of the decision procedure, and thus is the first one to be considered for purchasing selections.

Table-2

The decision makers' evaluation of the suppliers for delivery performance

Supplier	**Delivery**				
	D_1	D_2	D_3	D_4	D_5
T_1	M&G	M	G	G	M
T_2	VP	VG	G	VG	M
T_3	M&G	M&G	P&M	G	P
T_4	VG	P	G&VG	G	M&G
T_5	M	VP	P&M	P	VP&P
T_6	P&M	VG	G	M	G&VG
T_7	VP&P	P&M	VG	P	M&G
T_8	G	VP&P	VP	P	P&M
T_9	P&M	G	M	M&H	VP
T_{10}	VP&P	G	VP	P&M	M
T_{11}	G	M	VP&P	VP	M&G
T_{12}	G	M&G	VP	M	M&G

T_{13}	VP	P&M	G&VG	P&M	M
T_{14}	VG	G&VG	G&VG	P&M	M&G
T_{15}	P	P	VG	M	G&VG
T_{16}	P&M	P	M	G	G&VG
T_{17}	G	VP&P	VG	G&VG	P&M
T_{18}	VG	VP	G&VG	M&G	VP&M
T_{19}	M	M	P&M	VP&P	M
T_{20}	M&G	G	VP&P	VG	G

Table-3

The decision makers' evaluation of the suppliers for quality performance

Supplier	**Quality**				
	D_1	**D_2**	**D_3**	**D_4**	**D_5**
T_1	VP&P	M&G	G&VG	M	M
T_2	P	G	G	G&VG	M
T_3	VG	VG	P	G&VG	P
T_4	VG	VG	P	VG	M&G
T_5	P&M	G	P	G&VG	VP&P
T_6	M	VG	P	VP	G&VG
T_7	VG	M&G	M	VP&P	M&G
T_8	VP	M&G	G	M	P&M
T_9	P&M	G	M&G	P	VP
T_{10}	P&M	VP	VP	P	M
T_{11}	VP	M&G	VP&P	VG	M&G
T_{12}	G&VG	M&VG	M	G&VG	M&G
T_{13}	P&M	M	M&G	G&VG	M
T_{14}	P&M	P&M	VG	P&M	M&G
T_{15}	P	G&VG	VG	G	G
T_{16}	M&G	G	G	M	VP
T_{17}	VP	G	VG	M	VP&P
T_{18}	M&G	P&M	G	P	VP
T_{19}	VG	G&VG	G	M&G	G&VG
T_{20}	M	P&M	P	VP&P	G&VG

Table-4

The decision makers' evaluation of the suppliers for flexibility performance

Supplier	**Flexibility**				
	D_1	**D_2**	**D_3**	**D_4**	**D_5**
T_1	VG	M	M&G	G&VG	G
T_2	P	M	M	VP	VG
T_3	VP&P	P&M	VG	M	G&VG
T_4	G&VG	G&VG	M&G	G	P&M
T_5	P	M&G	VG	VG	M&G
T_6	VP&P	VP	M	VP	VP
T_7	VP	VP	VP	P&M	VP
T_8	VG	VP	M&G	G	G&VG

T_9	G&VG	VG	G&VG	M	VP&P
T_{10}	V&VG	G	G	VG	P
T_{11}	VP	M&G	VP	M&G	M
T_{12}	VP	VP&P	**M**	VPP	M
T_{13}	G	P	VP&P	M&G	P&M
T_{14}	VP&P	P	M&G	G	M&G
T_{15}	M&G	VP&P	M&G	VPP	GG
T_{16}	G	VG	P	VP	VGVG
T_{17}	M&G	P&M	M	VG	G&VG
T_{18}	VG	G&VG	VG	M&G	G
T_{19}	M	VP	G	P&M	P&M
T_{20}	M	P	P&M	G	VG

Table-5

The decision makers' evaluation of the suppliers for service performance

Supplier	**Service**				
	D_1	**D_2**	**D_3**	**D_4**	**D_5**
T_1	M	P	VG	VP	VP
T_2	M	P & M	VP	G & VG	G
T_3	P	G	P	VG	VG
T_4	M&G	P	P & M	P	VG
T_5	VP&P	P	P & M	M	P & M
T_6	P&M	P	G & VG	G	VG
T_7	G	G & VG	P & M	G	M & G
T_8	G	VP & P	M & G	VG	G
T_9	M&G	VP & P	M	P	G
T_{10}	VG	G & VG	VG	M & G	P & M
T_{11}	P&M	G	P & M	G	VP & P
T_{12}	VG	P & M	P & M	VP	M & G
T_{13}	VG	P & M	VP & P	G	P
T_{14}	G	VG	M & G	M	M
T_{15}	VP	P	G	M	M
T_{16}	P	VP	M	VP	VG
T_{17}	P&M	G & VG	M	G	VP
T_{18}	G	VG	P	VG	P
T_{19}	P	P	M & G	VG	P & M
T_{20}	P	M	VP & P	P & M	P & M

Table-6

The average linguistic ratings of supplier alternatives for delivery criteria

Supplier	**Delivery**			
T_1	0.42	0.62	0.68	0.88
T_2	0.50	0.66	0.66	0.78
T_3	024	0.44	0.62	0.82
T_4	0.46	0.66	0.76	0.88
T_5	0.06	0.18	0.28	0.48
T_6	0.46	0.66	0.76	0.88
T_7	0.22	0.38	0.54	0.70
T_8	0.12	0.24	0.34	0.54
T_9	0.24	0.40	0.52	0.72
T_{10}	0.18	0.30	0.40	0.60
T_{11}	0.24	0.36	0.46	0.66

T_{12}	0.30	0.46	0.58	0.78
T_{13}	0.18	0.34	0.50	0.66
T_{14}	0.46	0.66	0.86	0.94
T_{15}	0.34	0.54	0.58	0.70
T_{16}	0.30	0.50	0.60	0.76
T_{17}	0.40	0.56	0.70	0.82
T_{18}	0.34	0.46	0.60	0.72
T_{19}	0.18	0.34	0.44	0.64
T_{20}	0.46	0.62	0.72	0.88

Table-7

The average linguistic ratings of supplier alternatives for quality criteria

Supplier	**Quality**			
T_1	0.30	0.46	0.60	0.76
T_2	0.42	0.62	0.66	0.82
T_3	0.44	0.64	0.68	0.76
T_4	0.54	0.74	0.80	0.88
T_5	0.24	0.40	0.54	0.70
T_6	0.34	0.50	0.54	0.66
T_7	0.34	0.50	0.66	0.82
T_8	0.24	0.40	0.52	0.72
T_9	0.18	0.34	0.46	0.66
T_{10}	0.06	0.18	0.24	0.44
T_{11}	0.28	0.40	0.56	0.72
T_{12}	0.48	0.68	0.86	0.94
T_{13}	0.30	0.50	0.66	0.82
T_{14}	0.22	0.42	0.66	0.82
T_{15}	0.52	0.72	0.76	0.88
T_{16}	0.36	0.52	0.58	0.78
T_{17}	0.34	0.46	0.50	0.66
T_{18}	0.18	0.34	0.46	0.66
T_{19}	0.58	0.78	0.92	1.00
T_{20}	0.18	0.34	0.48	0.64

Table-8

The average linguistic ratings of supplier alternatives for flexibility criteria

Supplier	**Flexibility**			
T_1	0.52	0.72	0.82	0.94
T_2	0.28	0.44	0.44	0.60
T_3	0.34	0.50	0.64	0.76
T_4	0.42	0.62	0.82	0.94
T_5	0.44	0.64	0.76	0.88
T_6	0.06	0.10	0.14	0.34
T_7	0.00	0.04	0.10	0.30
T_8	0.46	0.62	0.72	0.84
T_9	0.46	0.62	0.74	0.82
T_{10}	0.52	0.72	0.76	0.88
T_{11}	0.18	0.30	0.42	0.62
T_{12}	0.12	0.20	0.28	0.48
T_{13}	0.18	0.34	0.50	0.70
T_{14}	0.24	0.40	0.56	0.76
T_{15}	0.24	0.36	0.56	0.76

T_{16}	0.44	0.60	0.60	0.72
T_{17}	0.40	0.60	0.76	0.88
T_{18}	0.62	0.82	0.92	1.00
T_{19}	0.18	0.34	0.46	0.66
T_{20}	0.34	0.54	0.60	0.76

Table-9

The average linguistic ratings of supplier alternatives for service criteria

Supplier	**Service**			
T_1	0.22	0.34	0.34	0.50
T_2	0.30	0.46	0.56	0.72
T_3	0.44	0.64	0.64	0.76
T_4	0.22	0.42	0.54	0.70
T_5	0.06	0.22	0.38	0.58
T_6	0.40	0.60	0.70	0.82
T_7	0.42	0.62	0.78	0.94
T_8	0.46	0.62	0.72	0.88
T_9	0.24	0.40	0.50	0.70
T_{10}	0.50	0.70	0.86	0.94
T_{11}	0.24	0.40	0.56	0.76
T_{12}	0.22	0.38	0.56	0.72
T_{13}	0.28	0.44	0.54	0.70
T_{14}	0.46	0.66	0.72	0.88
T_{15}	0.24	0.40	0.40	0.60
T_{16}	0.22	0.34	0.34	0.50
T_{17}	0.30	0.46	0.58	0.72
T_{18}	0.44	0.64	0.64	0.76
T_{19}	0.22	0.42	0.54	0.70
T_{20}	0.06	0.22	0.38	0.58

Table-10

Fuzzy suitability index values for the supplier alternatives

Supplier	**Fuzzy Preference Index**			
	c	**a**	**B**	**d**
T_1	0.2101	0.4301	0.4921	0.7047
T_2	0.2005	0.4175	0.4362	0.6442
T_3	0.1800	0.4050	0.4858	0.6876
T_4	0.2287	0.4529	0.5695	0.7641
T_5	0.1177	0.2859	0.4261	0.5897
T_6	0.1552	0.3338	0.3847	0.5855
T_7	0.1055	0.2349	0.3557	0.5855
T_8	0.1573	0.3227	0.4202	0.6483
T_9	0.1562	0.3234	0.4301	0.6457
T_{10}	0.1587	0.3245	0.4089	0.6219
T_{11}	0.1206	0.2514	0.3676	0.6038
T_{12}	0.1433	0.3179	0.4170	0.6406
T_{13}	0.1154	0.2970	0.4109	0.6359
T_{14}	0.1753	0.3953	0.5282	0.7506
T_{15}	0.1766	0.3826	0.4450	0.6576
T_{16}	0.1833	0.3351	0.4195	0.6241
T_{17}	0.1963	0.4025	0.4925	0.6890
T_{18}	0.2134	0.4292	0.5060	0.7006

T_{19}	0.1451	0.3451	0.4209	0.6605
T_{20}	0.1615	0.3533	0.4337	0.6465

Table-11

Ranking of the supplier alternatives

Ranking	Supplier (Ti)	Ranking Value
1	T_4	0.6191
2	T_{18}	0.6057
3	T_{14}	0.6001
4	T_1	0.5977
5	T_{17}	0.5911
6	T_3	0.5736
7	T_2	0.5617
8	T_{16}	0.5590
9	T_{15}	0.5554
10	T_9	0.5464
11	T_8	0.5447
12	T_{20}	0.5441
13	T_{10}	0.5356
14	T_{12}	0.5309
15	T_{19}	0.5308
16	T_6	0.5128
17	T_{13}	0..5092
18	T_5	0.5083
19	T_{11}	0.5042
20	T_7	0.4868

Conclusion

There have been many methods proposed for the modeling of the supplier selection process. However they cannot meet the real choice process with performance evaluation because most of the existing methods are mathematical models. But this is a real critical subject for a decision maker that can result in choosing a supplier with an insufficient performance.
The method that this paper presents here is an easy and realistic approach for supplier selection. The most important part of the FSSA is that it gives a concrete result by recording the purchasing experts' previous experience and processes these with fuzzy logic arithmetic. Briefly, results in this paper not only provide a valuable reference for decision makers in selecting a right vendor for a right product but also provide a useful algorithm for many organizations that use the decision rule to improve their total operation cost in the real world. In this regard, the proposed algorithm presented in this paper may be more realistic for some real world problems. Ranking of supplier alternatives with an example problem generated results which are consistent with the expectations. So it indicates some flexibility to cover many decisions in fuzzy scenarios. The proposed algorithm can be extended in several ways. As a further study, it is possible to develop this method by using numerical performance criteria via DFA in order to use objective and subjective evaluations together.

References

[1] V. Albino and A.C. Garavelli, A neural network application to subcontractor rating in construction firms, *Int. J. Proj. Manage.*, 16(1) (1998), 9-14.

[2] G. Barbarosoglu and T. Yazeac, An application of the analytic hierarchy process to the supplier selection problem, *Prod. Invent. Manage. J.*, 1st Quarter (1997), 14-21.

[3] J.F. Baldwin and N.C.F. Guild, Comparision of fuzzy sets on the same decision space, *Fuzzy Sets & Syst.*, 2(1979), 213-231.

[4] D.N. Buri, Managing product quality through strategic purchasing, *Sloon Management Review*, 30(1) (1989), 39-47.

[5] I.M. Campos, and A. Munoz, A subjective approach fr ranking fuzzy subsets, *Fuzzy Sets & Syst.*, 29(1989), 145-153.

[6] P.T. Change, and E.S. Lee, Ranking of fuzzy sets based on the concept of existence, *Comp. Math. with Applic.*, 27(9) (1994), 121.

[7] S.S. Chaudhry, F.G. Forest and J.L. Zydiak, Vendor selection with price breaks, *Euro. J. Oper Res.*, 70(1993), 52-66.

[8] S.H. Chen, Ranking Fuzzy numbers with maximising set and minimising set, *Fuzzy Sets & Syst.*, 17(1958), 113-129.

[9] L. De Boer, Operations research in support of purchasing, Design of a toolbox for supplier selection, *PhD. Thesis*, University of Twente, Enschede, The Netherlands, (1998).

[10] L. De Boer, A review of methods supporting supplier selection, *Euro. J. Purch. Supply Manage.*, 7(2001), 75-89.

[11] D. Dubois, and H. Prade, Ranking fuzzy numbers in the setting of possibility theory, *Inform. Sci.*., 30(1983), 183-224.

[12] L.M. Ellram and A.S. Carr, Strategic purchasing: A history and review of the literature, *Int. J. Purch. Mat. Manage*, 30(2) (1994), 1018.

[13] P. Fortemps and M. Roubens, Ranking and defuzzification methods based on area compensation, *Fuzzy Sets & Syst.*, 82(1996), 319-330.

[14] G.D. Holt, Which contractor selection methodology? *Int. J Khoo*, L.P. Tor. S.B. and S.S.G. Lee, The potential of intelligent software agents in the World Wide Web in the automated part procurement, *Int. J. Purch. Mater. Manage*, 34(1) (1998), 46-52.

[15] K. Kim and K.S. Park, Ranking fuzzy numbers with index of optimism, *Fuzzy Sets and Svst.*, 35(1990), 143-150.

[16] C.C. Li, Y.P. Fun and J.s. Hung, A new measure for supplier performance evaluation, *IIE Trans. Oper. Eng.*, 29(1997), 753-758.

[17] G.S. Liang and M.J. and, Ranking fuzzy numbers with integral value, *Fuzzy Sets & Svst.*, 50(1992), 247-255.

[18] H. Min, International supplier selection: A multi-attribute utility approach, *Int. J. Phys. Distrib. Logist. Manage.*, 24(5) (1994), 24-33.

[19] R.M. Monczka, R.J. Treeka. and R.B. Handfield, *Purchasing and Supply Chain Management*, (South-Western : Cincinnati, OH), (1998).

[20] R. Narasimhan, An analytic approah to supplier selection, *J. Purch. Supply Manage.*, 1(1983), 27-32.

[21] R.L. Nydick and R.P. Hill, Using the analytic hierachy process to structure the supplier selection procedure, *Int. J. Purch. Mater. Manage.*, 28(2) (1992), 31-36.

[22] A.C. Pan, Allocation of order quantities among suppliers, *J. Purch. Mater. Manage.*, 25(2) (1989), 36-39.

[23] V. Peneva and I. Popchev., Comparision of clusters from fuzzy numbers, *Fuzzy Sets & Syst.*, 97(1998), 75-81.

[24] A. Petroni and M. Braglia, Vendor selection using principal component analysis, *J. Supply Chain Manage*, 36(2) (2000), 63-69.

[25] P.A. Raj and d.N. Kumar, Ranking alternatives with fuzzy weights using maximizing set and minimizing set, *Fuzzy Sets and Systems*, 105(1999), 365-375.

[26] B. Ronen and d. Trietsch, A decision support system for purchasing management of large projects, *Oper. Res.*, 36(6) (1988), 882-890.

[27] E.C. Rosenthal, J.L. Zydiak, and S.S. Chaudhry, Vendor selection with bunding, *Deci. Sci.*, 26 (1) (1995), 35-48.

[28] A.A. Sadrian and Y.S. Yoon, A procurement decision support system in business volume discount environments, *Oper. Res.*, 42(1) (1994), 14-23.

[29] J. Sarkis and S. Talluri, A model for strategic supplier selection, *In Proceedings of the 9th International IPSERA Conference*, edited by M. Leenders, Richard lvey Business School, London, Ontario, (2000), 652-661.

[30] D.L. Smytka, and M.W. Clemens, Total cost supplier selection model: A case study, *Int. J Purch. Mater. Manage*, 29(1) (1993), 42-49.

[31] W.R. Soukup, Supplier selection strategies, *J. Purch. Mater. Manage*, 23(3) (1987), 7-12.

[32] E. Timmerman, An approach to vendor performance evaluation, *J. Purch. Supply Manage.*, 1(1986), 27-32.

[33] R.J. Vekurka, J. Choobineh and L. Vadi, A prototype expert system for the evaluation and selection of potential suppliers, *Int. J. Oper. Prod. Manage*, 16(12) (1996), 106-127.

[34] C.V. Altrock, *Fuzzy Logic and Neuro Fuzzy Applications on Business and Finance*, (Prentice - Hall: Englewood Chifts. NJ), (1997).

[35] C.A. Wether, *A Decision Support System Using Multicriteria Techniques for Vendor Selection*, (University Microfilms International: Ann Arbor, MI), (1991).

[36] C.A. When and A. Desai, Determination of paths to vendor market efficiency using parallel coordinates representation: A negotiation tool for buyers, *European Journal of Operational Research*, 90(1996), 142-155.

[37] C.A. Weber, J.R. Current and A. Desai, An optimisation approach to determining the number of vendors to employ, *Int. J. Supply Chain Manage*, 5(2) (2000), 90-98.

[38] R.F. Williams, *Purchasing Criterial for the Inherently Complex New Product*, (University Microfilms International: Ann Arbor, MI), (1984).

[39] L.A. Zadeh, *Fuzzy Sets. Inform. Cont.*, 8(1965), 338-353.

[40] G. Zenz, *Purchasing and the Management of Materials*, (Wiley: NY), (1981).

[41] H.-J. Zimmerman and P. Zysno, Decisions and evaluations by hierachical aggregation of information, *Fuzzy Sets & Syst*., 10(1983), 243-266.