DYNAMIC VENDOR SELECTION: A FUZZY AHP APPROACH

Saroj Koul*
Jindal Global Business School,
OP Jindal Global University,
NCR of Delhi, 131001 (INDIA)
skoul@jgu.edu.in

Rakesh Verma
Operations Management Group,
National Institute of Industrial Engineering (NITIE),
Mumbai, 400087 (INDIA)
rakeshverma@nitie.edu

ABSTRACT

In the ever-changing business world, appropriate vendor selection can be crucial in supply chain management. Dynamic models supporting vendors over time are not always crisp; rather they involve a high degree of fuzziness and uncertainty in real life situations. This paper proposes a dynamic model with uncertainty based on Fuzzy AHP for long-term strategic vendor selection problems. The selection of partnership suppliers is illustrated by this methodology.
http://dx.doi.org/10.13033/ijahp.v4i2.25
Keywords: Analytic Hierarchy Process, AHP, Dynamic model, Fuzzy Sets, Supply Chain Management

1. Introduction

In today's highly competitive and interrelated manufacturing environment, materials represent a substantial part of the value of products. Because material cost accounts for such a high percentage of the total cost, the key objective of the purchasing department ought to be obtaining the right quality of a product in the right quantity from the right source at the right time. The right source can provide the right quality of material on time at a reasonable price (Heizer and Render, 2001).

Supplier selection and evaluation are very important to the success of a manufacturing firm because the cost and quality of goods and services sold are directly related to the cost and quality of goods and services purchased. Therefore, purchasing and supplier selection have an important role in the supply chain process (Hartley and Choi, 1996; Degraeve, Labro, and Roodhooft, 2000). Traditionally, vendors are selected based on their ability to meet the quality requirements, their delivery schedule, and the price

* Corresponding author

offered. Vendor selection and evaluation is a common problem in the process of acquiring the necessary materials to support the outputs of an organization. The problem involves finding and periodically evaluating the most suitable vendor(s) based on various vendors' capabilities. This is especially difficult when a purchase is complex, of high-dollar value and perhaps critical. A process of formal vendor evaluation and ranking is also necessary. The process of vendor selection is a problem-solving process which involves the work of problem definition, formulation of criteria, qualification, and choice.

The supplier selection process is a multi-objective decision encompassing many tangible and intangible factors in a hierarchical manner. Traditional methodologies of the supplier selection process in research literature include the cost-ratio method, the categorical method, weighted-point evaluations, mathematical programming models and statistical or probabilistic approaches (Yan, Yu, and Cheng, 2003; Oliveria and Vadi, 2002). Dickson has identified 23 important criteria in the study of supplier decision-making (Dickson, 1966). Weber et al. (2000) has compiled many articles in this area, and has used a linear weighting model for supplier selection. Linear weighting models place a weight on each criterion and provide a total score for each supplier by summing up the supplier's performance on the criteria multiplied by these weights. Hokey Min (1994) used a multi-attribute utility approach in international supplier selection. Using interpretative structural modeling in their study, Anukal Mandal and S. G. Desmukh (1994) developed an analytical framework which combines qualitative and quantitative factors. Motwani et al. (1999) developed a model for the supplier selection process in developing countries. Youssef et al. (1996) developed a simple model for supplier evaluation and selection in an advanced manufacturing technology environment. Mathematical programming models use the techniques of linear programming, mixed integer programming, and goal programming to determine vendor selection and order quantity decisions simultaneously. The purpose of mathematical programming models is to select several vendors in order to minimize or maximize an objective function subject to both vendor and buyer constraints. Competitive advantage is often determined by the effectiveness of an organization's supply chain, and as a result the evaluation and selection of suppliers has become an increasingly important management activity. But the evaluation process is complex as much of the data are difficult to obtain and ambiguous or vague to interpret. In addition, the dynamic global environment of changing exchange rates, economic conditions, and technical infrastructure, demand that the pool of potential suppliers be re-evaluated periodically.

Drawbacks of the above approaches include neglect of multi-period planning horizons for vendor selection, and selection of vendors based on experience and intuition. These approaches are obviously subjective and their weaknesses are clear. To overcome these problems, we use the Fuzzy Analytic Hierarchy Process to propose the decision model.

2. Dynamic Fuzzy AHP Method

The Analytic Hierarchy Process is a powerful and flexible decision-making process to help people set priorities and make the best decision when both qualitative and quantitative aspects need to be considered. By reducing complex decisions to a series of one-on-one comparisons and then synthesizing the results, many researchers have concluded that AHP is a useful, practical and systematic method for vendor rating (Barbarosoglu and Yazgac, 1997); it has certainly been applied successfully. However, in many practical cases the human preference model is uncertain and decision-makers might be reluctant or unable to assign exact numerical values to the comparison judgments. For instance, when evaluating different suppliers, the decision-makers are usually unsure about their level of preference due to incomplete and uncertain information about possible suppliers and their performances. Since some of the supplier evaluation criteria are subjective and qualitative, it is very difficult for the decision-maker to express the strength of his preferences and to provide exact pair-wise comparison judgments. For this reason, a methodology based on fuzzy AHP can help to reach an effective decision. In this way, we can deal with the uncertainty and vagueness in the decision process. Fuzzy AHP consists of deriving the local priorities from these fuzzy preference ratios, which are subsequently aggregated to form the global priorities. The fuzzy AHP computes fuzzy priorities based on arithmetic operations for fuzzy triangular (or trapezoidal) numbers. To be able to use the fuzzy arithmetic operations, specific assumptions about the forms of membership functions are required. However, the most important criticism directed at fuzzy arithmetic operations is their failure to address the issue of consistency. There is no explicit articulation on what would constitute an inconsistent comparison matrix within the fuzzy AHP context, and equally important on how inconsistent information should be handled. Lacking a mechanism to exclude inconsistent data, fuzzy priorities so obtained are likely to be flawed (Zimmerman, 1991; Buckley, Feuring, and Hayashi, 2001). In addition to combining the AHP approach with other methods, Zaim et al. (2003) has discussed a fuzzy analytic hierarchy based approach for supplier selection in the area of marketing. Chan and Kumar (2007) extended it by including risk factors involved in global supplier selection to handle the fuzziness of the data involved in deciding the preferences of different decision variables. Chen et al. (2007) also employed a hierarchical model using triangular fuzzy numbers to deal with supplier selection problems. Benyoucef and Mustafa (2007) validated the design of the supplier selection system for a hospital and its underlying fuzzy AHP model. Saaty and Tran (2007) invalidate the fuzzifying numerical judgments in the Analytic Hierarchy Process. In fuzzy AHP, preferences between alternatives are determined by making fuzzy pairwise comparisons. If appropriate with the fuzzy AHP method, vendor selection criteria are determined and compared to the sub criteria and then the importance level for each criterion is found with the calculation of the process according to the given hierarchy structure. A decision making process arises to select the vendors. According to the purchasing department of any manufacturing company the following criteria set is constructed for supplier selection in subsection 3.1. In a fuzzy pairwise comparison, the decision maker examines two alternatives by considering one criterion and indicates a preference. These comparisons are made using a preference scale, which assigns numerical values to different levels of preference. The standard preference scale used for AHP is a 1-9 scale which lies between "equal importance" to "extreme importance". However, a 1 to 5 ratio scale is applied for fuzzy AHP.

Table 1
Fuzzy AHP Scale

Statement	TFN
Absolute (row to column)	(7/2, 4, 9/2)
Very strong (row to column)	(5/2, 3, 7/2)
Fairly strong (row to column)	(3/2, 2, 5/2)
Weak (row to column)	(2/3, 1, 3/2)
Equal	(1, 1, 1)
Weak (column to row)	(2/3, 1, 3/2)
Fairly strong (column to row)	(2/5, 1/2, 2,/3)
Very strong (column to row)	(2/7, 1/3, 2/5)
Absolute (column to row)	(2/9, 1/4, 2/7)

Source: Tolga et al, 2005

In this study, the framework of a feasible region of relative weights was adopted. First, allowing the feasible region to include tolerance deviations of the fuzzy ratios, we define fuzzy consistency as the existence of relative weights within the region. Second, we devise a maximum/minimum set ranking method to derive a crisp ranking from the global fuzzy weights (Noci and Toletti, 2000; Leung and Cao, 2000). The following steps of fuzzy AHP proposed by Chang (1996) have been utilized in selecting vendors during a multi-period.

According to the method of Chang's extent analysis, each object is taken and an analysis for each goal is performed respectively. Therefore, m extent analysis values for each object can be obtained with the following signs:

$$M_{g^i}^1, M_{g^i}^2, ..., M_{g^i}^m, \quad i = 1,2,...,n.$$

where $M_{g^i}^j \quad (j = 1,2,...,m.)$ all are TFNs. The steps of Chang's extent analysis (Chang, 1996) are as follows:

Step 1: The value of fuzzy synthetic extent with respect to the ith object is defined as:

$$S_i = \sum_{j=1}^{m} M_{g^i}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g^i}^j \right]^{-1} \quad (1)$$

To obtain $\sum_{j=1}^{m} M_{g^i}^j$, the fuzzy addition operation of m extent analysis values for a particular matrix is performed such as:

$$\sum_{j=1}^{m} M_{g^i}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \quad (2)$$

and the following is obtained $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g^i}^{j} \right]$, by performing the fuzzy addition operation of $M_{g^i}^{j}$ $(j = 1,2,...,m.)$ such that:

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g^i}^{j} \right] = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i \right) \quad (3)$$

and $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g^i}^{j} \right]^{-1}$ can be calculated by the inverse of Eq. (3), as follows:

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g^i}^{j} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \right) \quad (4)$$

Step 2: As $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ are two triangular fuzzy numbers, the degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ is defined as:

$$V(M_2 \geq M_1) = \sup_{y \geq x} \left[\min(\mu_{M_1}(x), \mu_{M_2}(y)) \right] \quad (5)$$

and can be expressed as follows:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) \quad (6)$$

$$= \begin{cases} 1 & if\ m_2 \geq m_1 \\ 0 & if\ l_1 \geq u_2 \\ \dfrac{(l_1 - u_2)}{(m_2 - u_2) - (m_1 - l_1)} & otherwise \end{cases} \quad (7)$$

Figure 1 (Kahraman et al., 2004) illustrates Eq. (6) where d is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2}. To compare $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$, we need both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$.

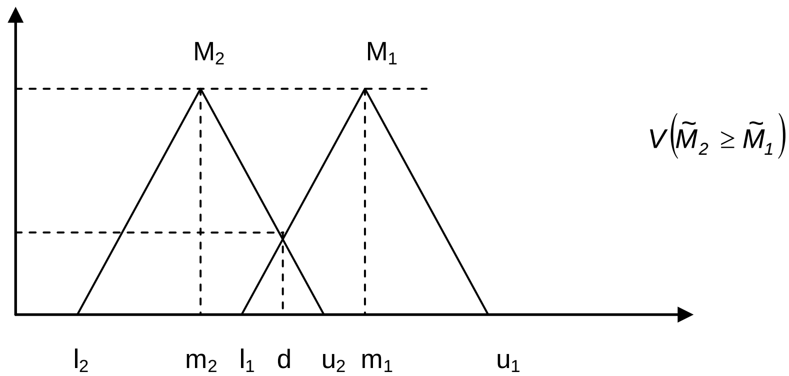

Figure 1 Intersection between M_1 and M_2 (Kahraman et al., 2004)

Step 3: The degree possibility for a convex fuzzy number to be greater than k convex fuzzy $M_i \; (i = 1,2,...,k)$ numbers can be defined by:

$$V(M \geq M_1, M_2, ..., M_k) = V[(M \geq M_1) \; and (M \geq M_2) \; and \; ...and \; (M \geq M_k)]$$

$$= \min V(M \geq M_i), \; i = 1,2,...,k \qquad (8)$$

Assume that

$$d(A_i) = \min V(S_i \geq S_k) \text{ for } k = 1,2,...,n; k \neq i. \qquad (9)$$

Then the weight vector is given by

$$W^{'} = (d^{'}(A_1), d^{'}(A_2), ..., d^{'}(A_n))^T \qquad (10)$$

where $A_i \; (i = 1,2,...,n)$ are the n elements.

Step 4: Via normalization, the normalized weight vectors are:

$$W = (d(A_1), d(A_2), ..., d(A_n))^T \qquad (11)$$

where W is a non-fuzzy number.

3. An Illustrative Example

This numerical example presents a mathematical model to select suppliers in a multi-period environment.

3.1. Define the criteria for vendor selection

The main objective is the selection of the best supplier for a firm in a dynamic environment. The problem has three levels of hierarchy in kth period where (k=1, 2, 3).

The analytic time periods are the past (*k*=1), present (*k*=2), and near future (*k*=3). Thus, the decision makers can estimate the relative weights ratios for each pair of alternatives under every attribute as well as the relative weights ratios for the attributes. Application of common criteria to all suppliers makes objective comparisons possible. The criteria which are considered here in the selection of the best supplier in dynamic environment are:

- Quality of the product
- Delivery
- Overall cost of the product
- Flexibility in service

The hierarchy of the selection criteria and decision alternatives (i.e., suppliers) in a dynamic environment can be seen in Figure 2. In the hierarchy, the overall objective (i.e., the best supplier) is placed at level 1, criteria at level 2, and the suppliers alternatives at level 3 in kth period where k=1,2,3.

The above mentioned criterion helps decide the best supplier for an organization in each period. The preference of one over another has been decided by the decision makers. Human judgment may not always be crisp and therefore the evaluation scale used by decision makers is illustrated Table 1.

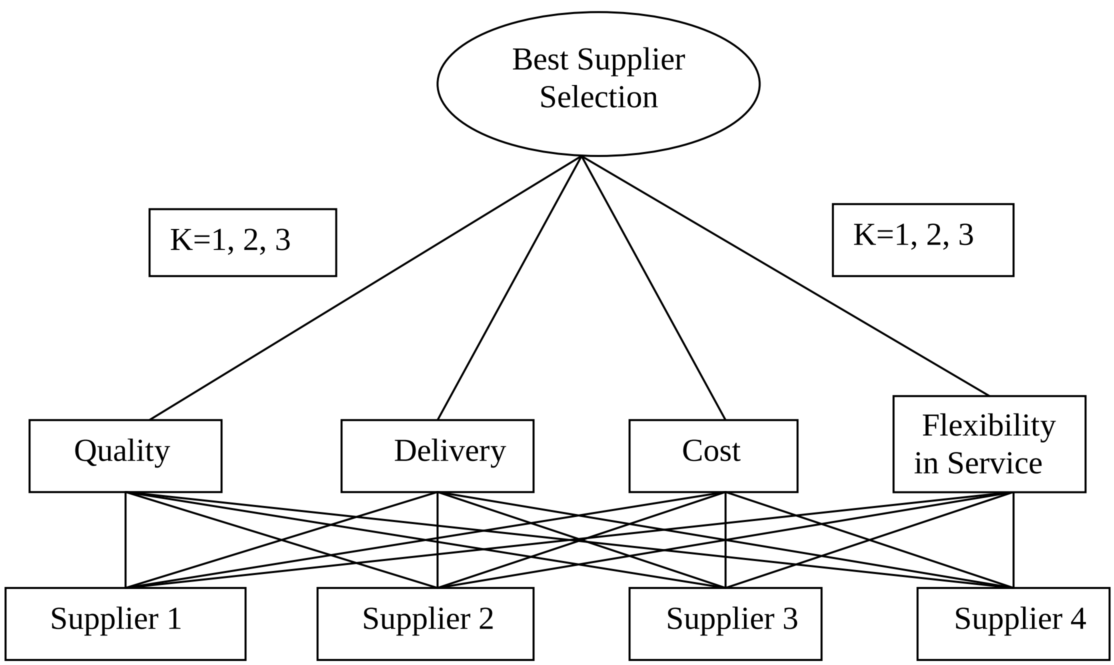

Figure 2 Dynamic hierarchy for supplier selection

The fuzzy pair wise reciprocal judgments matrix of the decision maker for each criterion with respect to the overall objective (i.e. selecting the best supplier) (see Table 2), and for each supplier with each of the criterion (see Table 3-6) in each of the three period are determined with the help of FAHP scale defined in Table 1.

Table 2
The criterion fuzzy pairwise comparison matrix in k period (k=1, 2, 3)

	k	Quality	Delivery	Cost	Flexibility In Service
Quality	1	(1,1,1)	(2/3,1,3/2)	(3/2,2,5/2)	(3/2,2,5/2)
	2	(1,1,1)	(5/2,3,7/2)	(3/2,2,5/2)	(3/2,2,5/2)
	3	(1,1,1)	(3/2,2,5/2)	(5/2,3,7/2)	(7/2,4,9/2)
Delivery	1	(2/3,1,3/2)	(1,1,1)	(2/5,1/2,2/3)	(2/3,1,3/2)
	2	(2/7,1/3,2/5)	(1,1,1)	(2/5,1/2,2/3)	(2/3,1,3/2)
	3	(2/5,1/2,2/3)	(1,1,1)	(5/2,3,7/2)	(5/2,3,7/2)
Cost	1	(2/5,1/2,2/3)	(3/2,2,5/2)	(1,1,1)	(1,1,1)
	2	(2/5,1/2,2/3)	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)
	3	(2/7,1/3,2/5)	(2/7,1/3,2/5)	(1,1,1)	(3/2,2,5/2)
Flexibility in Service	1	(2/5,1/2,2/3)	(2/3,1,3/2)	(1,1,1)	(1,1,1)
	2	(2/5,1/2,2/3)	(2/3,1,3/2)	(2/5,1/2,2/3)	(1,1,1)
	3	(2/9,1/4,2/7)	(2/7,1/3,2/5)	(2/5,1/2,2/3)	(1,1,1)

Table 3 Fuzzy judgments for alternatives with respect to Quality in k period (k=1, 2, 3)

Quality	k	Supplier 1	Supplier 2	Supplier 3	Supplier 4
Supplier 1	1	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(7/2,4,9/2)
	2	(1,1,1)	(2/5,1/2,2/3)	(5/2,3,7/2)	(3/2,2,5/2)
	3	(1,1,1)	(2/3,1,3/2)	(3/2,2,5/2)	(3/2,2,5/2)
Supplier 2	1	(2/5,1/2,2/3)	(1,1,1)	(2/5,1/2,2/3)	(3/2,2,5/2)
	2	(3/2,2,5/2)	(1,1,1)	(2/5,1/2,2/3)	(2/3,1,3/2)
	3	(2/3,1,3/2)	(1,1,1)	(2/5,1/2,2/3)	(2/3,1,3/2)
Supplier 3	1	(2/5,1/2,2/3)	(2/7,1/3,2/5)	(1,1,1)	(3/2,2,5/2)
	2	(2/7,1/3,2/5)	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)
	3	(2/5,1/2,2/3)	(3/2,2,5/2)	(1,1,1)	(2/5,1/2,2/3)
Supplier 4	1	(2/9,1/4,2/7)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)
	2	(2/5,1/2,2/3)	(2/3,1,3/2)	(2/5,1/2,2/3)	(1,1,1)
	3	(2/5,1/2,2/3)	(2/3,1,3/2)	(3/2,2,5/2)	(1,1,1)

Table 4
The alternatives fuzzy pair-wise comparison matrix with respect to criteria Delivery in period (k=1, 2, 3)

Delivery	k	Supplier 1	Supplier 2	Supplier 3	Supplier 4
Supplier 1	1	(1,1,1)	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)
	2	(1,1,1)	(2/9,1/4,2/7)	(2/3,1,3/2)	(2/5,1/2,2/3)
	3	(1,1,1)	(2/3,1,3/2)	(1,1,1)	(2/5,1/2,2/3)
Supplier 2	1	(2/3,1,3/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)
	2	(7/2,4,9/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)
	3	(2/3,1,3/2)	(1,1,1)	(2/5,1/2,2/3)	(2/3,1,3/2)
Supplier 3	1	(2/3,1,3/2)	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)
	2	(2/3,1,3/2)	(2/5,1/2,2/3)	(1,1,1)	(2/3,1,3/2)
	3	(1,1,1)	(3/2,2,5/2)	(1,1,1)	(2/5,1/2,2/3)
Supplier 4	1	(2/3,1,3/2)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)
	2	(3/2,2,5/2)	(2/5,1/2,3/2)	(2/3,1,3/2)	(1,1,1)
	3	(3/2,2,5/2)	(2/3,1,3/2)	(3/2,2,5/2)	(1,1,1)

Table 5
The alternatives fuzzy pair-wise comparison matrix with respect to criteria Cost in k period (k=1, 2, 3)

Cost	k	Supplier 1	Supplier 2	Supplier 3	Supplier 4
Supplier 1	1	(1,1,1)	(3/2,2,5/2)	(2/3,1,3/2)	(5/2,3,7/2)
	2	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(2/3,1,3/2)
	3	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(2/3,1,3/2)
Supplier 2	1	(2/5,1/2,2/3)	(1,1,1)	(2/3,1,3/2)	(3/2,2,5/2)
	2	(2/5,1/2,2/3)	(1,1,1)	(1,1,1)	(3/2,2,5/2)
	3	(2/5,1/2,2/3)	(1,1,1)	(1,1,1)	(3/2,2,5/2)
Supplier 3	1	(2/3,1,3/2)	(2/3,1,3/2)	(1,1,1)	(3/2,2,5/2)
	2	(2/5,1/2,2/3)	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)
	3	(2/5,1/2,2/3)	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)
Supplier 4	1	(2/7,1/3,2/5)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)
	2	(2/3,1,3/2)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)
	3	(2/3,1,3/2)	(2/5,1/2,2/3)	(3/2,2,5/2)	(1,1,1)

Table 6
The alternatives fuzzy pair-wise comparison matrix with respect to criteria Flexibility in Service in k period (k=1, 2, 3)

Flexibility in Service	***k***	***Supplier 1***	***Supplier 2***	***Supplier 3***	***Supplier 4***
Supplier 1	1	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)
	2	(1,1,1)	(2/9,1/4,2/7)	(2/3,1,3/2)	(2/5,1/2,2/3)
	3	(1,1,1)	(2/3,1,3/2)	(2/3,1,3/2)	(2/5,1/2,2/3)
Supplier 2	1	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)
	2	(7/2,4,9/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)
	3	(2/3,1,3/2)	(1,1,1)	(2/3,1,3/2)	(2/5,1/2,2/3)
Supplier 3	1	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(2/3,1,3/2)
	2	(2/3,1,3/2)	(2/5,1/2,2/3)	(1,1,1)	(2/3,1,3/2)
	3	(3/2,1,3/2)	(2/3,1,3/2)	(1,1,1)	(2/5,1/2,2/3)
Supplier 4	1	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/3,1,3/2)	(1,1,1)
	2	(3/2,2,5/2)	(2/5,1/2,2/3)	(2/3,1,3/2)	(1,1,1)
	3	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)

In order to identify the computation procedures the pair-wise judgments from Table 3 for period 3 are evaluated as follows:

Quality	***Supplier 1***	***Supplier 2***	***Supplier 3***	***Supplier 4***
Supplier 1	(1,1,1)	(2/3,1,3/2)	(3/2,2,5/2)	(3/2,2,5/2)
Supplier 2	(2/3,1,3/2)	(1,1,1)	(2/5,1/2,2/3)	(2/3,1,3/2)
Supplier 3	(2/5,1/2,2/3)	(3/2,2,5/2)	(1,1,1)	(2/5,1/2,2/3)
Supplier 4	(2/5,1/2,2/3)	(2/3,1,3/2)	(3/2,2,5/2)	(1,1,1)

$$Supplier_{1Q} = (4.667, 6, 7.5) \otimes (1/22.667, 1/18.00, 1/14.267)$$
$$= (0.206, 0.333, 0.526)$$

$$Supplier_{2Q} = (2.733, 3.5, 4.667) \otimes (1/22.667, 1/18.00, 1/14.267)$$
$$= (0.121, 0.194, 0.327)$$

$$Supplier_{3Q} = (3.30, 4.0, 4.833) \otimes (1/22.667, 1/18.00, 1/14.267)$$
$$= (0.146, 0.222, 0.339)$$

$$Supplier_{4Q} = (3.567, 4.5, 5.667) \otimes (1/22.667, 1/18.00, 1/14.267)$$
$$= (0.157, 0.250, 0.327)$$

After determining these results, these fuzzy values are compared by using Eq. (7):

$$V(Supplier_{1Q} \geq Supplier_{2Q}) = 1, V(Supplier_{1Q} \geq Supplier_{3Q}) = 1,$$
$$V(Supplier_{1Q} \geq Supplier_{4Q}) = 1$$

$$V(Supplier_{2Q} \geq Supplier_{1Q}) = 0.466, V(Supplier_{2Q} \geq Supplier_{3Q}) = 0.867,$$
$$V(Supplier_{2Q} \geq Supplier_{4Q}) = 0.753$$

$$V(Supplier_{3Q} \geq Supplier_{1Q}) = 0.545, V(Supplier_{3Q} \geq Supplier_{2Q}) = 1,$$
$$V(Supplier_{3Q} \geq Supplier_{4Q}) = 0.867$$

$$V(Supplier_{4Q} \geq Supplier_{1Q}) = 0.697, V(Supplier_{4Q} \geq Supplier_{2Q}) = 1,$$
$$V(Supplier_{4Q} \geq Supplier_{3Q}) = 1$$

Then priority weights are calculated by using Eq. (8):

$$d'(Supplier_{1Q}) = \min(1,1,1) = 1$$
$$d'(Supplier_{2Q}) = \min(0.466, 0.867, 0.753) = 0.466$$
$$d'(Supplier_{3Q}) = \min(0.545, 1, 0.867) = 0.545$$
$$d'(Supplier_{4Q}) = \min(0.697, 1, 1) = 0.697$$

Therefore, the weight vector from Table 3 for period 3 is calculated as:

$$W_Q^{Supplier} = (1, 0.466, 0.545, 0.697)$$

After the normalization of these values priority weights with respect to criteria Quality are calculated as:

$$W_Q^{Supplier} = (0.397, 0.187, 0.261, 0.154)$$

The same systematic approach is considered for the other evaluations, and priority weights are expressed correspondingly in Tables 7, 8, 9 and 10 as follows. Table 11 represents the priority weights of the four suppliers in all the three periods, and is obtained by multiplying the priority weights of criteria to the suppliers' weights with respect to all criteria in each period respectively.

4. Discussion of Results

As we can see in Figure 3, the priority of quality improvement is important for every supplier for all of the periods. We can also observe from Table 7 that cost is more important than delivery in the first two periods. Figure 4 shows the trend of supplier's priority; Supplier 1 is the most preferred in the first two periods, but Supplier 4 over performed Supplier 1 by a small margin in third period. Similarly Supplier 2 is the most preferred over Supplier 3 in the first two periods, but in the third period Supplier 3 over performed Supplier 2 with by a large margin. Hence, we can conclude that if we have to select only one supplier then Supplier 1 will be chosen for the first two periods, and Supplier 4 for the third period. However, when we have selected two or more suppliers then there will be an option as shown in Table 12.

Table 7
The priority weights of Criteria in period 1-3

***Criteria* ▼**	***Period* ▼**		
	1	***2***	***3***
Quality	0.40	0.65	0.66
Delivery	0.19	0.00	0.34
Cost	0.26	0.35	0.00
Flexibility in Service	0.15	0.00	0.00

Table 8
The priority weights of suppliers with respect to all criteria in period 1

***Suppliers* ▼**	***Criteria***			
	Quality	***Delivery***	***Cost***	***Flexibility in Service***
1	1.00	0.24	0.47	0.53
2	0.00	0.37	0.23	0.39
3	0.00	0.27	0.30	0.04
4	0.00	0.12	0.00	0.04

Table 9
The priority weights of suppliers with respect to all criteria in period 2

Suppliers ▼	Criteria			
	Quality	Delivery	Cost	Flexibility in Service
1	0.42	0.00	0.53	0.00
2	0.23	0.76	0.33	0.86
3	0.31	0.00	0.03	0.00
4	0.03	0.24	0.11	0.14

Table 10
The priority weights of suppliers with respect to all criteria in period 3

Suppliers ▼	Criteria			
	Quality	Delivery	Cost	Flexibility in Service
1	0.37	0.14	0.43	0.15
2	0.17	0.18	0.26	0.15
3	0.20	0.26	0.02	0.15
4	0.26	0.42	0.29	0.55

Table 11
The priority weights of suppliers in periods 1-3

Suppliers ▼	Period		
	1	2	3
1	0.65	0.46	0.29
2	0.19	0.27	0.17
3	0.13	0.22	0.22
4	0.03	0.06	0.31

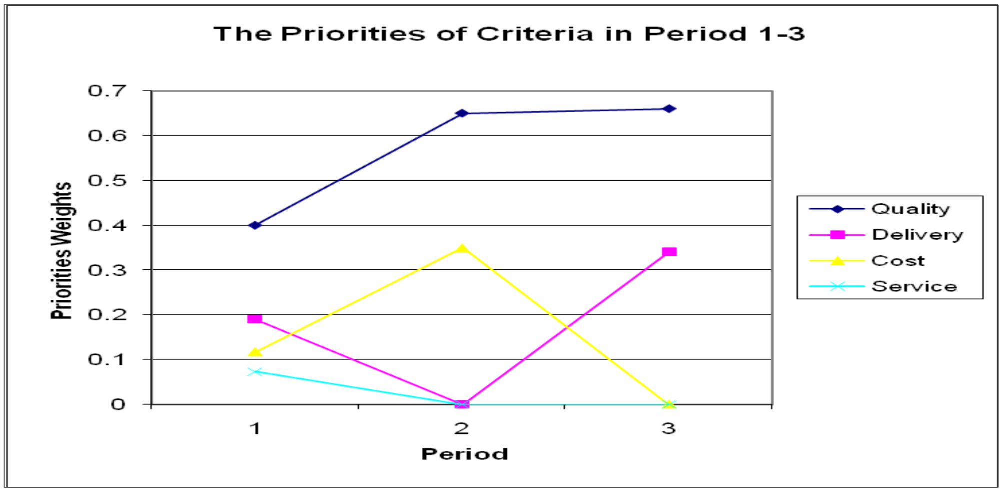

Figure 3 Priorities of Criteria in three periods

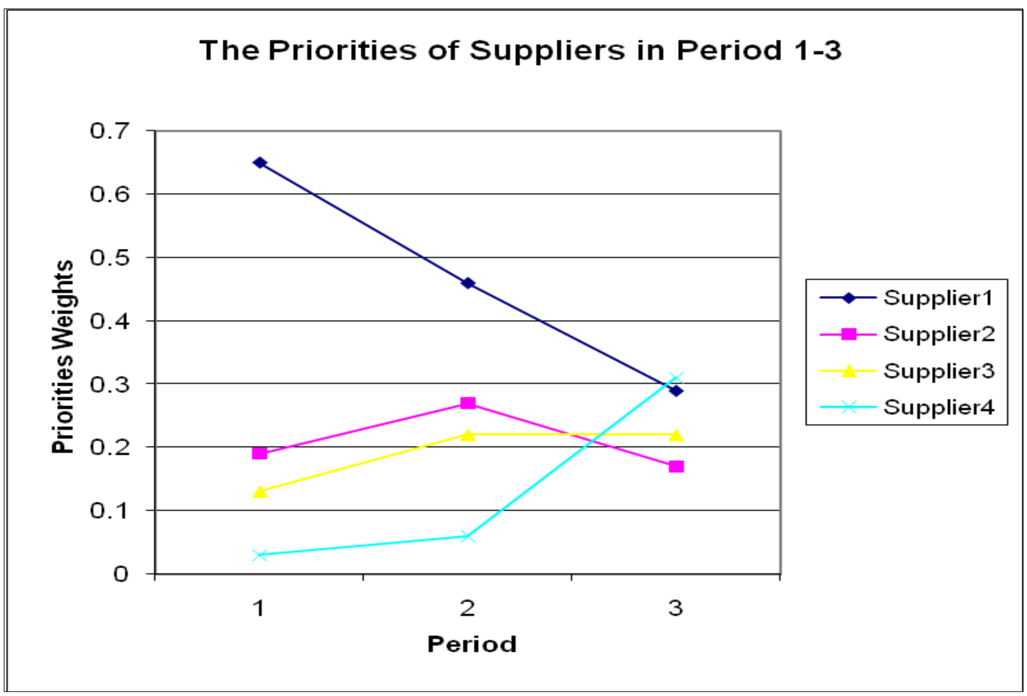

Figure 4 Priority weights of Suppliers in three periods

Table 12
Order of Supplier selection in three periods

No. of Suppliers ▼	**Period**		
	1	*2*	*3*
1	S1	S1	S4
2	S1, S2	S1, S2	S1, S4
3	S1, S2, S3	S1, S2, S3	S1, S3, S4
4	S1, S2, S3, S4	S1, S2, S3, S4	S1, S2, S3, S4

Fuzzy AHP uses intersection operation while evaluating comparison results. The result of the fuzzy intersection can be obtained as zero (e.g. the priority weights of criteria in period 2 is $(0.65, 0.00, 0.35, 0.00)^T$ which means that the corresponding criterion has no importance. This finding raises the question "if this criterion is of concern to the decision, then how can it have a zero importance?" In fact, it is an ordinary consequence of fuzzy logic. Fuzzy pair wise comparisons show that if a criterion is less important than all of the others, then relatively this criterion has no importance and the weight is zero. Even if it is declared that a criterion is relevant for the decision making process, it has no importance when compared with the others. In the classic AHP method, deterministic values and operations do not permit the situation "having zero weight". But, if a criterion is evaluated as "less than all of the others", then the numerical result of this situation, the weight of this criterion, would be near to zero. Furthermore, the weight can descend to 0.01 which means that this criterion is not so important to the final decision. Fuzzy AHP totally neglects the criterion which is less important than the others whereas classical AHP uses this criterion with a small weight. The presentation of this additional information for the decision maker, that there is no difference between the existence or nonexistence of such a criterion, can be an advantage for fuzzy AHP. Therefore, the decision maker can focus on the more important criteria. Linguistic and subjective evaluations take place in questionnaire form. Each linguistic variable has its own numerical value in the predefined scale. In classical AHP these numerical values are exact numbers, whereas in the fuzzy AHP method they are intervals between two numbers with a most likely value. As is the nature of the human beings, linguistic values can change from person to person. In these circumstances, taking the fuzziness into account will result in less risky decisions. Here, classical and fuzzy methods are not competitors when the same conditions are present. The important point is that if the information/evaluations are certain, the classical method should be preferred. If the information/evaluations are not certain, the fuzzy method should be preferred. In recent years, because of the characteristics of information and decision makers, probable deviation should be integrated into the decision making processes. Because of this a fuzzy version has been developed for each decision making method. The fuzzy AHP method is a natural result of this.

5. Conclusions

Customarily in global supply chain management, companies must select suitable suppliers over a long period of time. In dynamic business environments, attributes and weights may change over time and the actual decision may not be crisp, but rather fuzzy in nature. Traditional multiple attribute decision-making methods may not solve the long-term performance measurement problems in a fuzzy environment. In this methodology, one cannot find a consistent process for fuzzy inputs and crisp weights and the consistency index method is not appropriate because of the fuzziness. In fact, Chang's fuzzy AHP comprises such a mechanism during the pairwise calculations when the membership values or possibilities are compared and the intersections are obtained. Furthermore, the fuzziness concept has some bias such as the inconsistency of the decision maker. This paper proposes a dynamic approach based on Fuzzy AHP for supplier selection problems that can help reach an effective decision. This makes it possible to deal with the uncertainty and vagueness in the decision process. Therefore, for each decision making method, a fuzzy version has been developed. Fuzzy AHP method is a natural result of this. For future work, we will try to extend the Fuzzy AHP method to an *Intuitionistic Fuzzy* AHP method to select the suppliers.

ACKNOWLEDGEMENTS

The authors are grateful to the reviewers for their valuable suggestions that have made the paper more systematic and instructive.

REFERENCES

Barbarosoglu, G., and Yazgac, T. (1997). An application of the analytic hierarchy process to the supplier selection problem. *Production and Inventory Management Journal*, *38(1)*, 14-21.

Bellman, R.E., and Zadeh, L.A. (1970). Decision making in a fuzzy environment. *Management Sciences*, *17*, 141-164.

Benyoucef, M., and Canbolat, M. (2007). Fuzzy AHP-based supplier selection in e-procurement. *International Journal of Services and Operations Management*, *3(2)*, 172 – 192.

Buckley J.J., Feuring T., and Hayashi Y., (2001). Fuzzy hierarchical analysis revisited. *European Journal of Operational Research*, *129*, 48-64.

Chan, F.T.S. and Kumar, N. (2007) Global supplier development considering risk factors using fuzzy extended AHP-based approach, *Omega*, *35(4)*, 417-431.

Chang, D. (1996). Application of the extent analysis method on fuzzy AHP. *European Journal of Operational Research*, *95*, 649-655.

Chen, C.T., Ching-T.L., and Huang, S.F. (2006). A fuzzy approach for supplier evaluation and selection in supply chain management. *International Journal of Production Economics*, *102(2)*, 289-301.

Degraeve, Z., Labro, E., & Roodhooft, F., (2000). An evaluation of vendor selection models from a total cost of ownership perspective. *European Journal of Operational Research*, *125*, 34-58.

Dickson, G., (1966). An analysis of vendor selection systems and decisions. *Journal of Purchasing*, *2(1)*, 5-17.

Hartley, J.L., & Choi, T.Y., (1996). Supplier development: Customer as a catalyst of process change. *Business Horizons*, *39(4)*, 37-40.

Heizer, J.& Render, B. (2001). *Operations Management*. Upper Saddle River: Prentice Hall, 431-457.

Kahraman C., Cebeci, U., and Ruan, D. (2004) Multi-attribute comparison of catering service companies using fuzzy AHP: the case of Turkey. *International Journal of Production Economics*, *87*, 171–184.

Leung, L.C., and Cao, D. (2000). Theory and Methodology, on consistency and ranking of alternatives in fuzzy AHP. *European Journal of Operational Research*, *124*, 102-113.

Mandal, A., and Deshmukh, S.G. (1994). Vendor selection using interpretive structural modeling. *International Journal of Operations & Production Management*, *14 (6),* 52-59.

Motwani, J., Youssef, M., Kathawala, Y., and Futch, E. (1999). Supplier selection in developing countries: a model development. *Integrated Manufacturing System*, *10(3),* 154-161.

Muralidharan, C., Anantharaman, N., and Deshmukh, S.G. (2002). A multi-criteria group decision-making model for supplier rating. *The Journal of Supply Chain Management*, *Fall,* 22-33.

Min, H., (1994). International Supplier Selection. *International Journal of Physical Distribution & Logistics Management*, *24(5),* 24-33.

Noci, G., & Toletti, G., (2000). Selecting quality-based programmes in small firms: A comparison between the fuzzy linguistic approach and the analytic hierarchy process. *International Journal of Production Economics, 67*, 113-133.

Oliveira, R.C., & Lourenço, J.C., (2002). A multi-criteria model for assigning new orders to service suppliers. *European Journal of Operational Research*, *139(2),* 390-399.

Saaty, T.L. (1980). *The Analytical Hierarchy Process*. New York, NY: McGraw-Hill.

Saaty, T.L and Tran, L. T., (2007). On the invalidity of fuzzifying numerical judgments in the Analytic Hierarchy Process. *Mathematical and Computer Modelling*, *46(7-8),* 962 – 975.

Tolga, E., Demircan, M. L. & Kahraman, C. (2005) Operating System Selection Using Fuzzy Replacement Analysis and Analytic Hierarchy Process. *International Journal of Production Economics*, *97*, 89-117.

Weber, C. A., Current, J. R., & Desai, A. (2000). An optimization approach to determining the number of vendors to employ. *Supply Chain Management: An International Journal*, *2(5),* 90-98.

Yan, H., Yu, Z., & Cheng, T.C.E. (2003). A Strategic model for supply chain design with logical constraints: Formulation and solution. *Computers & Operations Research*, *30(14),* 2135-2155.

Youssef, M.A., Zairi, M., & Mohanty, B. (1996). Supplier selection in an advanced manufacturing technology environment: an optimization model. *Benchmarking for Quality Management & Technology*, *3(4)*, 60-72.

Zadeh, L.A., (1965). Fuzzy Sets. *Information and Control*, *8*, 338-353.

Zaim, S., Sevkli,M. and Tarim,M. (2003). Fuzzy analytic hierarchy based approach for supplier selection, *Journal of Euromarketing*, *12(3/4)*, 147-176.

Zimmermann, H.J. (1991). *Fuzzy Set Theory and Its Applications*. Dordrecht: Kluwer Academic Publishers.