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Full Length Research Paper

A Fuzzy AHP approach for selecting a global supplier in pharmaceutical industry

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Our study looks into the strategy that should be pursued for raw material procurement by a pharmaceutical firm operating in Turkey. In this paper, pharmaceutical research companies and food industry chemists operating in the global market in the pharmaceutical industry are examined and a suitable supply strategy is suggested for a company operating in Turkey under the specified criteria. The supplier selection is a multi-criterion problem which includes both qualitative and quantitative criteria. This paper proposes a fuzzy analytic hierarchy process (fuzzy-AHP) to efficiently tackle both quantitative and qualitative criteria involved in selection of global supplier in pharmaceutical industry. Four main criteria and thirteen sub-criteria were identified for supplier selection in this problem. The number of suppliers to be selected under these criteria was identified as four. A numerical example presented illustrates the different selection criteria to select the best supplier in pharmaceutical industry.

Key words: Supply chain, fuzzy logic, fuzzy analytic hierarchy process (AHP), Multi Criteria decision making problem.

INTRODUCTION

Supplier selection, which can be defined as the determination of the possible quality, quantity, price and vendor of the raw materials, semi-finished products and other materials that will be used in production, is one of the important steps of production. Today, the concept of globalization is also seen in the supply business. Working with suitable suppliers significantly affects the competitiveness of businesses. From this angle, selection of the suitable supplier becomes an important task for procurement decision-makers in companies (Spekman, 1988).

In the increasingly competitive world of business and industry, identifying the suppliers and managing the supply chain have become an important factor. Competition has become globalized, and innovations have moved from company-level to supply chain-level. In hi-tech companies in particular, the materials and services purchased correspond to 80% of the total cost (Weber et al., 1991). This percentage shows us the importance of supplier selection and supplier suitability for a company. Around 80% of the compounds used in pharmaceutical production are procured through importing. Hence, as seen in many areas, companies operating in the pharmaceutical industry are in need of new supply strategies in accordance with use of external resources. The pharmaceutical industry can be defined as a sector focusing on the research, development, testing and final production of medicine and treatments. Companies operating in the pharmaceutical industry want to have the ability to conduct researches, increase efficiency, ensure product diversity, offer their products worldwide, and be effective players in the emerging markets. In addition, the safety and reliability of the produced product is an important element in the pharmaceuticals industry. The purity of the compound used in the product is one of the most important criteria in supplier selection.

Supplier selection problems usually consist of multiple criteria that contradict each other. However, multiple criteria decision-making (MCDM) analyses assume that these criteria are independent from each other (Yang et al., 2008). Many models have been developed for

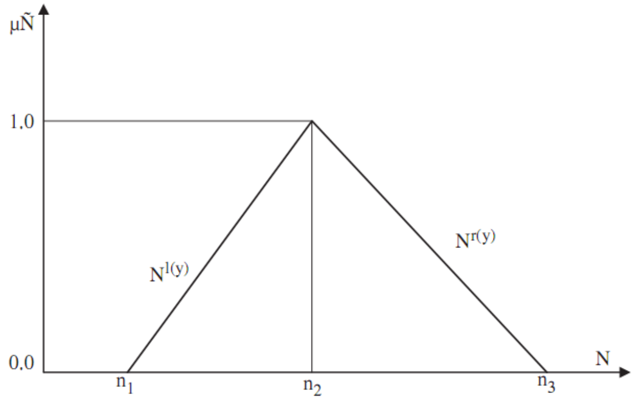

Figure 1. Triangular fuzzy number.

solution of MCDM problems. Some of these include the preference ranking organization method developed by Brans et al. (1985), the analytical hierarchy process (AHP) (Chan, 2010; Gungor, 2010), discrete choice analysis (Verma, 1998), and data envelopment analysis (DEA) (Weber, 2000; Narasimhan, 2001). However, the criteria used in the MCDM encountered in real life are generally not uncertain and completely independent criteria. To overcome this fuzziness of uncertainly and preference, it is suggested to use the fuzzy logic developed by Zadeh (1965) and designed to formulate ambiguous, uncertain, indefinite results. Bellman (1970) suggests this concept as a decision-making method for fuzzy environments. The fuzzy set theory has been used in the solution of many multiple criteria decision-making (MCDM) problems. Buyukozkan (2011), Nepal (2010), Kilincci (2011), Dagdeviren (2009), Ansarinejad (2011) and Chan (2008) can be given as examples to these studies.

The supplier selection problem is one of the major problems in raw material supply, especially for pharmaceutical firms. In the global market, it is of great importance that these raw materials are produced, stored, made available on time and in desired quantities, and delivered to buyers under desired conditions. The chemical compounds used in pharmaceutical production can easily deteriorate. Therefore, it is an important criterion that chemical is handled appropriately and under appropriate conditions during the supply process. In addition, the purity levels of demanded compounds are of great importance for buyers.

Our study looks into the strategy that should be pursued for raw material procurement by a pharmaceutical firm operating in Turkey. Pharmaceutical research companies and food industry chemists operating in the global market in the pharmaceutical industry will be examined and a suitable supply strategy will be suggested for a company operating in Turkey under the specified criteria. A number of qualitative and quantitative criteria must be taken into consideration in the analysis of the supply chain. As a result of a survey conducted on 273 firms, Dickson (1966) suggested 23 criteria for evaluating suppliers (Weber et al., 1991, 1993). Based on these criteria, an attempt was made to identify the main criteria and sub-criteria. Moreover, these criteria also highlight qualities such as the purity level of the compound to be used in the pharmaceutical industry and the mode of packaging during handling, which are specifically included under main criteria. The fuzzy AHP method was used in evaluating the criteria.

FUZZY ANALYTICAL HIERARCHY PROCESS

Fuzzy sets

The theory of fuzzy sets has been developed by Zadeh (1965) to deal with the concept of partial truth values ranging from absolutely true to absolutely false. A fuzzy set is characterized by a membership function, which associates with each element x in X a real number in the interval [0, 1]. In this set the general terms such as ‘large’, ‘medium’ and ‘small’ are all linguistic values and they can also be represented by fuzzy numbers.

A fuzzy set is represented by putting a tilde ‘~’ on a letter. If n1, n2 and n3, respectively, denote the smallest possible value, the most promising value and the largest possible value that describe a fuzzy event then the triangular fuzzy number can be denoted as a triple (n1, n2, n3). A fuzzy number $\tilde{N}$ expresses the meaning of about N. A triangular fuzzy number $\tilde{N}$ is shown in Figure 1.

Some basic definitions of the fuzzy sets and fuzzy numbers after reviewing some of the past literatures (Zadeh, 1965; Buckley, 1985; Klir and Yuan, 1995; Ross, 1997) in this area are discussed.

Definition 1: The membership function of a triangular fuzzy number which associated with a real number in the interval [0, 1] can be defined as:

$$\mu_{\tilde{N}}(x) = \begin{cases} (x-n_1)/(n_2-n_1), & x \in [n_1, n_2] \\ (n_3-x)/(n_3-n_2), & x \in [n_2, n_3] \\ 0, & otherwise \end{cases} \quad (1)$$

A fuzzy number can be given by its corresponding left and right representation of each degree of membership:

$$\begin{aligned} \tilde{N} &= (N^{l(y)}, N^{r(y)}) \\ &= (n_1 + (n_2 - n_1)y, n_3 + (n_3 - n_2)y), \quad y \in [0,1] \end{aligned} \quad (2)$$

where l(y) and r(y) denote the left and right side representation of a fuzzy number respectively. A non-fuzzy number ‘r’ can be expressed as (r, r, r).

Definition 2: The height of a fuzzy set is the largest membership grade attained by any element in that set. A fuzzy set N in the universe of discourse Y is called normalized when the height of $\tilde{N}$ is equal to 1.

Definition 3: A matrix $\tilde{U}$ is called a fuzzy matrix if at least one element of it is a fuzzy number. The fuzzy sum and fuzzy subtraction of any two triangular fuzzy numbers are also a triangular fuzzy number, but the multiplication of any two triangular is an approximate triangular fuzzy number. That is,

$$\tilde{N}_1 \oplus \tilde{N}_2 = (n_{11} + n_{21}, n_{12} + n_{22}, n_{12} + n_{23}) \quad (3)$$

$$\tilde{N}_1 \Theta \tilde{N}_2 = (n_{11} - n_{21}, n_{12} - n_{22}, n_{12} - n_{23}) \quad (4)$$

$$\tilde{N}_1 \otimes \tilde{N}_2 = (n_{11}n_{21}, n_{12}n_{22}, n_{12}n_{23}) \quad (5)$$

$$\lambda \otimes \tilde{N}_1 = (\lambda n_{11}, \lambda n_{12}, \lambda n_{13}) \text{, where } \lambda > 0, \lambda \in R \quad (6)$$

$$\tilde{N}_1^{-1} = (\frac{1}{n_{11}}, \frac{1}{n_{12}}, \frac{1}{n_{13}}) \quad (7)$$

Extent analysis method on fuzzy AHP

Traditional methods of AHP can be of no use when uncertainty is observed in data of problems. To address such uncertainties, Zadeh (1965) for the first time introduced and used fuzzy sets theory. Based on the concept of fuzzy set theory, fuzzy AHP was originally introduced by van Laarhoven and Pedrycz (1983). Fuzzy AHP method has been widely used by various authors and turn out to be one of the best methods among various assessment methods (Weck et al., 1997). In Fuzzy AHP approach, triangular fuzzy numbers are used for the preferences of one criterion over another, and then by using Chang’s extend analysis method, the synthetic extend value of pairwise comparison is calculated (Chang, 1996).

Among the other fuzzy approaches, the extent analysis method has been employed in quite a number of applications due to its computational simplicity. The extent analysis method is used to consider the extent of an object to be satisfied for the goal, that is, satisfied extent. In the method, the ‘‘extent’’ is quantified by using a fuzzy number.

Wang et al. (2008) conclude that the extent analysis method is a method for showing to what degree the priority of one decision criterion or alternative is bigger than those of all the others in a fuzzy comparison matrix. The weights determined by this method do not represent the relative importance of decision criteria or alternatives at all. Therefore, one must be careful for estimating priorities from a fuzzy pair-wise comparison matrix.

Again since the use of the extent analysis method for solving fuzzy AHP problems may result in a wrong decision to be made, misapplications should be avoided.

The outlines of the extent analysis method on fuzzy AHP (Chang, 1992, 1996; Zhu et al., 1999) can be summarized as follows: If the object set is represented as X={x1, x2,…, xn} and the goal set as, U={u1,u2,….,um}, then according to the concept of extent analysis (Chang, 1992, 1996), each object is taken and extent analysis for each goal Ui is performed respectively. The fuzzy sets and notations discussed in this section are same as discussed in section 3. The algebraic operations on triangular fuzzy numbers follow the same mathematical rule and definitions discussed in section 3. The m extent analysis values for each object are denoted as:

$N_{oi}^1, N_{oi}^2, \ldots. N_{oi}^m,$ where i=1, 2… n.

where all the $N_{oi}^j (j = 1,2,\ldots.., m)$ are triangular fuzzy numbers. N_{oi}^m represents the value of the extent analysis of the ith object for mth goal.

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

$$F_i = \sum_{j=1}^{m} N_{oi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} N_{oi}^j \right]^{-1} \quad (8)$$

The value of $\sum_{j=1}^{m} N_{oi}^j$ can be found by performing the fuzzy addition operation of m extent analysis values from a particular matrix such that:

$$\sum_{j=1}^{m} N_{oi}^{j} = (\sum_{j=1}^{m} n_{1j}, \sum_{j=1}^{m} n_{2j}, \sum_{j=1}^{m} n_{3j}) \quad (9)$$

and the value of $\left[\sum_{i=1}^{n} j = \sum_{j=1}^{m} N_{oi}^j \right]$ can be obtained by performing the fuzzy addition operation of $N_{oi}^j (j = 1,2,\ldots.., m)$ such that

$$\sum_{i=1}^{n}\sum_{j=1}^{m} N_{oi}^{j} = (\sum_{i=1}^{m} n_{1j}, \sum_{i=1}^{m} n_{2j}, \sum_{i=1}^{m} n_{3j}) \quad (10)$$

and $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} N_{oi}^{j}\right]^{-1}$ can be calculated by the inverse of the previous Equation (10) as follows:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} N_{oi}^{j}\right]^{-1} = (\frac{1}{\sum_{i=1}^{n} n_{31}}, \frac{1}{\sum_{i=1}^{n} n_{2i}}, \frac{1}{\sum_{i=1}^{n} n_{1i}}) \quad (11)$$

The degree of possibility of $N_1 = (n_{11}, n_{12}, n_{13}) \geq N_2 = (n_{21}, n_{22}, n_{23})$ is defined as;

$$V(N_1 \geq N_2) = \sup_{x \geq y}\left[\min(\mu_{N1}(x), \mu_{N2}(y))\right] \quad (12)$$

when a pair (x, y) exists such that $x \geq y$ and $\mu_{n1}(x) = \mu_{n2}(y) = 1$, then we have

$$V(N_1 \geq N_2) = 1 \quad (13)$$

Since N_1 and N_2 are convex fuzzy numbers so,

$$V(N_1 \geq N_2) = 1 \text{ if } n_{11} \geq n_{21} \quad (14)$$

and $V(N_2 \geq N_1) = hgt(N_1 \cap N_2) = \mu_{N1}(d)$, (15)

where d is the ordinate of the highest intersection point D between μ_{n1} and μ_{n2} (shown in Figure 2).

When $N_1 = (n_{11}, n_{12}, n_{13})$ and $N_2 = (n_{21}, n_{22}, n_{23})$ then ordinate of D is computed by

$$V(N_2 \geq N_1) = hgt(N_1 \cap N_2) \quad (16)$$

$$= \frac{n_{11} - n_{23}}{(n_{22} - n_{23}) - (n_{12} - n_{11})} \quad (17)$$

For the comparison of N_1 and N_2 both the values of $V(N_1 \geq N_2)$ and $V(N_2 \geq N_1)$ are required.

The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers $N_i (i = 1,2,...,k)$ can be defined by

$V(N \geq N_1, N_2, ..., N_k) = V(N \geq N_1)$ and V$(N \geq N_2)$ and ... and V$(N \geq N_k)$ (18)

$= \min V(N \geq N_i)$, i=1, 2,....,k (19)

if m$(P_i) = \min V(F_i \geq F_k)$, (20)

for k=1, 2... n; $k \neq i.$ then the weight vector is given by

$$W_p = (m(P_1), m(P_2), ..., m(P_n))^T \quad (21)$$

where Pi (i=1,2,...,n) are n elements.

After normalizing Wp, we get the normalized weight vectors

$$W = (m(P_1), m(P_2), ..., m(P_n))^T \quad (22)$$

Where W is a non fuzzy number and this gives the priority weights of one alternative over other.

APPLICATION OF GLOBAL SUPPLIER SELECTION PROCESS IN PHARMACEUTICAL INDUSTRY

Fuzzy AHP procedure for the supplier selection problem

One of the most basic problems encountered in decision-making processes is the difficulty of defining the feelings, thoughts and decisions of people with an exact number. Generally, feelings, thoughts and decisions are expressed with a specific numerical range rather than an exact whole number, which can be a more realistic and reliable way. Hence, it has been demonstrated that good results were achieved with the AHP method although the classical AHP methods have failed to provide sound results in many applications. 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. Since some of the evaluation criteria are subjective and qualitative in nature, it is very difficult for the decision-maker to express the preferences using exact numerical values and to provide exact pairwise comparison judgments (Chan, 2008).

In this study, the linguistic variables corresponding to triangular fuzzy numbers were identified as in Kahraman et al. (2003). Then, extent analysis method was used to decide the final priority weights based on triangular fuzzy numbers and so-called as fuzzy extended AHP.

First of all, in order to identify the most suitable supplier

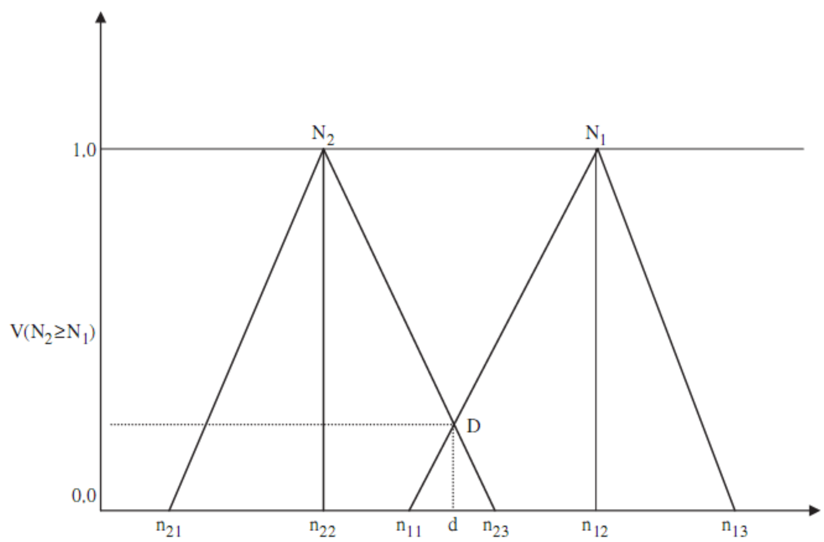

Figure 2. Intersection between N1 and N2.

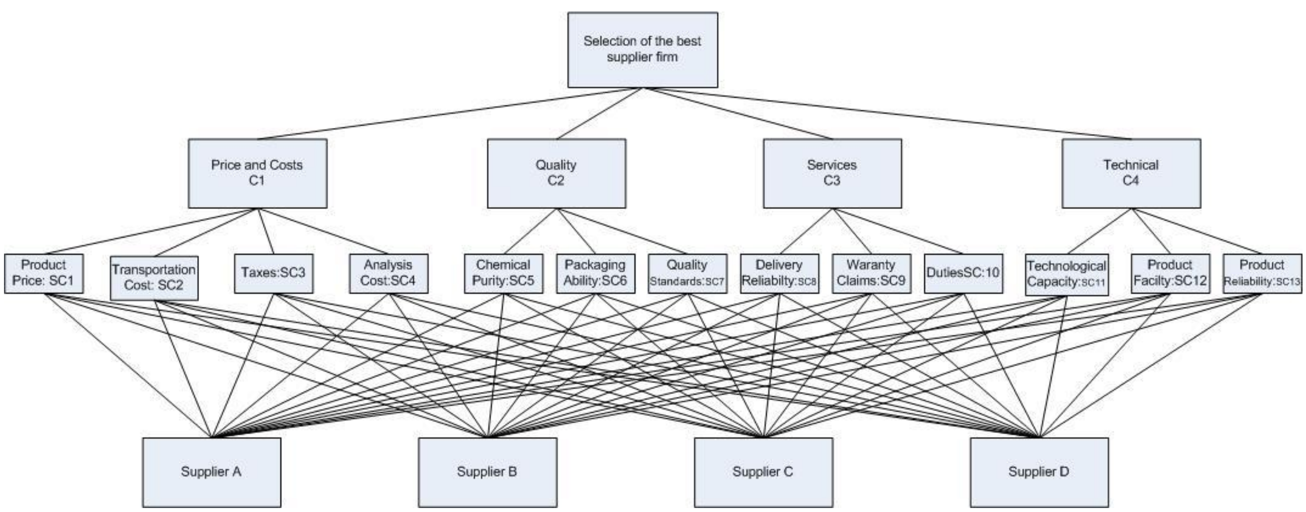

Figure 3. Proposed hierarchical structure for supplier selection.

company, which is the purpose of the study, the main criteria and sub-criteria were defined and a fuzzy AHP tree structure was built.

In this paper, criteria are denoted by Ci (i=1,2,3,4), sub-criteria by SCj (j=1,2,…,13) and alternatives by Supplier A, Supplier B, Supplier C and Supplier D. The hierarchy of the selection criteria, sub-criteria and decision alternatives in context with supplier selection can be seen from Figure 3.

To identify the criteria to be selected, interviews were made with the CEO and marketing manager of a pharmaceutical firm in Turkey, as competition is high between supplier firms in the global sense with regard to supply of the compounds used in the pharmaceutical industry. During these interviews, the main and sub-criteria included in our study were identified, in consideration also of the supplier selection criteria found in the literature. The preference of one over other is decided by the experts and researchers of the respective areas based on the questionnaire form (discussed in appendix). In line with these interviews, 4 main criteria were identified: price and cost, quality, services, and technical attributes. The 13 sub-criteria were as follows: product price, transportation cost, taxes, analysis cost, chemical purity, packaging ability, quality standards, delivery reliability, warranty claims, duties, technological capacity, product facility, and product reliability.

Price and costs

Firms basically go for either the lowest cost or the highest profit. Hence, the costs offered by the supplier are important. These costs are classified as product price, transportation cost, taxes, and analysis cost.

Product price: For firms, it is very important that the total cost is kept low. The price of the product or compound makes a significant part of the total cost. Hence, low product price is an important reason for choosing a specific supplier.

Transportation cost: In global supply, transportation costs are a criterion about which both firms and suppliers are very sensitive. Transportation cost is not merely the cost of sending the goods from one place to another, but also covers the transportation of the goods under appropriate conditions and in an appropriate way.

Taxes: In global competition, taxes vary both for the buyer and the supplier. The main reason for this variation is the differences between the import and export laws of each country. Hence, the laws of the country where the selected supplier operates may bring additional obligations. For this reason, these additional costs, which will be added onto the product cost, should be reviewed carefully.

Analysis cost: For pharmaceutical companies, the purity level of the delivered compound carries great importance in terms of the efficacy of the pharmaceutical that will be prepared. Thus, it is a basic motive to prefer when the supplier company has these analyses made and sends the relevant reports to the pharmaceutical company together with the product. If this is not the case, then the buyer will have to have the delivered compounds analyzed from its own pocket, which will add an extra cost line to the budget.

Quality

The main reason companies prefer a global supplier is that this enables them to reach high-quality products. Product quality can be defined more clearly by dividing it into sub-criteria.

Chemical purity: One criterion that is perhaps as important as price for the pharmaceutical industry is the purity level of the compound that will be used for manufacturing pharmaceuticals. As the purity of the compound increases, the efficacy of the produced pharmaceutical also increases. Hence, suppliers providing high-purity compounds are likely to be preferred.

Packaging ability: Correct packaging of the compounds to be used in the pharmaceuticals industry is highly important in preventing any deterioration in the chemical properties of the compound. While some chemicals require transportation and handling at certain temperatures, some must never contact air. Hence, the packaging method selected by the supplier is very important and varies for each compound.

Quality standards: It is important to choose suppliers with national and/or international quality certificates confirming their quality standards.

Services

Delivery reliability: In terms of the compounds supplied to the pharmaceutical industry, it is important that the compound is delivered to the customer with no structural deterioration or partial damage, that is, with no compromise from efficacy. Appropriate transportation and speedy delivery play an important role in selecting a supplier.

Warranty claims: It is also important that the compound carries the conditions and properties demanded by the customer at the time of delivery. A supplier’s ability to offer warranty and insurance terms to protect the product against any problems that may be encountered at this stage is highly effective in choosing a supplier.

Duties: Customs and tax laws that vary from country to country may lead to big problems especially for global companies. It becomes a serious problem for both the supplier and the customer when the compounds sent by the supplier are kept at the customs under inappropriate conditions and when they cannot be delivered to the customer on time. The supplier must take these possibilities into account and have relevant measures in place to counter them.

Technical

Technological capacity: It is important that the supplier is not only able to supply the current demands of the customers, but also able to readily adapt to and speedily deliver the future demands that may come from customers.

Product facility: Suppliers, particularly those operating in the pharmaceutical industry, should watch their customers well, and be able to identify and produce in

Table 1. The linguistic variables and their corresponding fuzzy numbers.

Linguistic variables	Fuzzy numbers
Equally preferred (EP)	(1, 1, 1)
Weakly preferred (WP)	(2/3, 1, 3/2)
Fairly strongly preferred (FSP)	(3/2, 2, 5/2)
Very strongly preferred (VSP)	(5/2, 3, 7/2)
Absolutely preferred (AP)	(7/2, 4, 9/2)

good time the compounds that the customer may demand. In addition, the suppliers should increase their capacities in consideration of the possibility of excess demand.

Product reliability: Product reliability refers to the process where the supplier is able to guarantee product reliability, produce the product to requested specifications and within the time frame specified by the customer, and delivers the product in good condition and in good time with no loss in technical attributes.

First the expert compared the main attributes with respect to the main goal; then the expert compared the sub-attributes with respect to the main attributes. At the end, the expert compared the supplier firms with respect to each sub-attribute. The expert used the linguistic variables to make the pair-wise comparisons. Then the linguistic variables were converted to triangular fuzzy numbers.

Following these comparisons, the weights of the criteria and sub-criteria were calculated using the Fuzzy AHP method. The calculation of the weights of the main criteria is given below as an example.

First of all, linguistic variables determined by the expert were converted into triangular fuzzy numbers with the help of Table 1. In order to find the priority characteristics of main criteria, the fuzzy synthetic extent values were calculated using equation 8. The different values of fuzzy synthetic extent with respect to the five different criteria are denoted by K1, K2, K3, and K4, respectively.

$$K_1 = (3.30,4.00,4.82) \otimes (22.54,17.53,16.38)^{-1} = (0.1464,0.2282,0.2943) \quad (23)$$

$$K_2 = (6.00,7.00,8.00) \otimes (22.54,17.53,16.38)^{-1} = (0.2662,0.3993,0.4884) \quad (24)$$

$$K_3 = (3.18,3.83,4.56) \otimes (22.54,17.53,16.38)^{-1} = (0.1411,0.2185,0.2784) \quad (25)$$

$$K_4 = (3.90,2.70,5.16) \otimes (22.54,17.53,16.38)^{-1} = (0.1730,0.1540,0.3150) \quad (26)$$

The degree of possibility of Ki over $K_i (i \neq j)$ was calculated by Equations (15) and (17).

$$V(K_2 \geq K_1) = 1, \quad V(K_1 \geq K_3) = 1, \quad V(K_1 \geq K_4) = 1,$$
$$V(K_2 \geq K_3) = 1, \quad V(K_2 \geq K_4) = 1, \quad V(K_3 \geq K_4) = 1. \quad (27)$$

$$V(K_2 \geq K_1) = \frac{0.2662 - 0.2943}{(0.2282 - 0.2943) - (0.3993 - 0.2662)} = 0.141 \quad (28)$$

Similarly, $V(K_3 \geq K_1) = 0.932$, $V(K_4 \geq K_1) = 0.695$, $V(K_3 \geq K_2) = 0.063$,

$$V(K_4 \geq K_2) = 0.166, \quad V(K_4 \geq K_3) = 0.729 \quad (29)$$

With Equation (20) the minimum degree of possibility was stated as below:

The fuzzy comparison matrices of sub-criteria and the weight vectors of each sub-criterion are shown in Tables 3 to 6.

min(c1) =min(0.141,1,1) =0.141

min(c2) =min(1,1,1)=1 (30)

min(c3) =min(0.932,0.063,1)=0.063

min(c4) =min(0.695,0.166,0.730)=0.166

Therefore the weight vector was given as W= (0.414, 1, 0.063, 0.166). After normalization process, we get the weight vector with respect to decision criteria C1, C2, C3, and C4 as

$$W_c = (0.102,0.669,0.046,0.121)^T$$

The complete result is also given in Table 2. The fuzzy comparison matrices of the sub-criteria with respect to criterions C1, C2, C3 and C4 are given in Tables 3 to 6.

The same calculation method was applied separately for each criterion, sub-criterion and alternative. Calculations dependent on all supplier alternatives were performed for each sub-criterion, from which 13 different table values were obtained. Tables 7 and 8 are given as examples.

The weights for sub-criteria included under each main criterion were calculated separately for each supplier, then these weights were multiplied with the weight per

Table 2. The fuzzy comparison matrix of criteria with respect to the overall objective.

Criteria	C1	C2	C3	C4	Weight
C1	(1,1,1)	(0.4,0.5,0.66)	(1.5,2,2.5)	(0.4,0.5,0.66)	0.102
C2	(1.5,2,2.5)	(1,1,1)	(2.5,3,3.5)	(1,1,1)	0.669
C3	(0.4,0.5,0.66)	(0.28,0.33,0.4)	(1,1,1)	(1.5,2,2.5)	0.046
C4	(1.5,2,2.5)	(1,1,1)	(0.4,0.5,0.66)	(1,1,1)	0.121

Table 3. The fuzzy comparison matrix of the sub-criteria with respect to criterion C1.

C1	SC1	SC2	SC3	SC4	Weight
SC1	(1,1,1)	(1.5,2,2.5)	(2.5,3,3.5)	(0.67,1,1.5)	0.503
SC2	(0.4,0.5,0.66)	(1,1,1)	(0.67,1,1.5)	(1.5,2,2.5)	0.250
SC3	(0.28,0.33,0.4)	(0.66,1,1.5)	(1,1,1)	(1.5,2,2.5)	0.224
SC4	(0.66,1,1.5)	(0.4,0.5,0.66)	(0.4,0.5,0.66)	(1,1,1)	0.022

Table 4. The fuzzy comparison matrix of the sub-criteria with respect to criterion C2.

C2	SC5	SC6	SC7	Weight
SC5	(1,1,1)	(1.5,2,2.5)	(0.67,1,1.5)	0.471
SC6	(0.4,0.5,0.66)	(1,1,1)	(0.4,0.5,0.66)	0.057
SC7	(0.66,1,1,5)	(1.5,2,2.5)	(1,1,1)	0.471

Table 5. The fuzzy comparison matrix of the sub-criteria with respect to criterion C3.

C3	SC8	SC9	SC10	Weight
SC8	(1,1,1)	(1.5,2,2.5)	(0.67,1,1.5)	0.451
SC9	(0.4,0.5,0.66)	(1,1,1)	(0.66,1,1.5)	0.225
SC10	(0.66,1,1.5)	(0.67,1,1.5)	(1,1,1)	0.324

Table 6. The Fuzzy comparison matrix of the sub-criteria with respect to criterion C4.

C4	SC11	SC12	SC13	Weight
SC11	(1,1,1)	(0.67,1,1.5)	(0.28,0.33,0.40)	0.053
SC12	(0.66,1,1.5)	(1,1,1)	(1.5,2,2.5)	0.434
SC13	(2.5,3,3.5)	(0.40,0.50,0.67)	(1,1,1)	0.512

each supplier, after which the products were added to create the weights dependent on sub-criteria. These calculations are given in Tables 9 to 12.

As a result, the priority weights of the suppliers (Supplier A, Supplier B, etc.) were combined with the criteria, and thus the potential suppliers were identified. Information regarding the identified suppliers is given in Table 13 and Figure 4.

Supplier selection problem calculations were done using the Excel macros created by the authors. According to the results in Table 13, it was determined that the best alternative for a Turkish firm operating in the pharmaceutical industry and seeking to purchase compounds from various international companies is A, followed closely by C. Sensitivity of each decision alternatives with respect to the sub-criteria and sensitivity of each decision alternatives with respect to the criteria is given in Figures 5 and 6, respectively.

Conclusion

Supplier selection problem is of strategic importance for businesses. When making this selection, it is important which criteria are to be selected and that the best solution is identified. This is particularly important for a company operating in the pharmaceutical industry and working mainly with international suppliers.

The study addressed the problem of procurement of compounds from international suppliers for research and production purposes by a company operating in the pharmaceutical industry in Turkey. Four main criteria and thirteen sub-criteria were identified for supplier selection in this problem. The number of suppliers to be selected under these criteria was identified as four. This multiple criteria decision-making analysis problem was solved using the fuzzy AHP method.

As a result of the calculations made, it was seen that

Table 7. The fuzzy comparison matrix of the decision alternatives with respect to sub-criterion SC1*.

Alternative	Supplier A	Supplier B	Supplier C	Supplier D	Weight
Supplier A	(1.0,1.0,1.0)	(1.50,2.00,2.50)	(0.67,1.00,1.50)	(2.50,3.00,3.50)	0.5172
Supplier B	(0.40,0.50,0.66)	(1.0,1.0,1.0)	(0.67,1.00,1.50)	(0.67,1.00,1.50)	0.1467
Supplier C	(0.67,1.00,1.50)	(0.67,1.00,1.50)	(1.0,1.0,1.0)	(1.50,2.00,2.50)	0.3358
Supplier D	(0.28,0.33,0.40)	(0.67,1.00,1.50)	(0.40,0.50,0.66)	(1.0,1.0,1.0)	0.0003

*Only two of a total of 13 tables are given here.

Table 8. The fuzzy comparison matrix of the decision alternatives with respect to sub-criterion SC2*.

Alternative	Supplier A	Supplier B	Supplier C	Supplier D	Weight
Supplier A	(1.0,1.0,1.0)	(0.40,0.50,0.66)	(0.67,1.00,1.50)	(1.50,2.00,2.50)	0.272
Supplier B	(1.50,2.00,2.50)	(1.0,1.0,1.0)	(1.50,2.00,2.50)	(1.50,2.00,2.50)	0.519
Supplier C	(0.67,1.00,1.50)	(0.40,0.50,0.66)	(1.0,1.0,1.0)	(0.67,1.00,1.50)	0.156
Supplier D	(0.40,0.50,0.66)	(0.40,0.50,0.66)	(0.67,1.00,1.50)	(1.0,1.0,1.0)	0.051

Table 9. Summary combination of priority weights: Sub-criteria of criterion C1.

Alternative		SC1	SC2	SC3	Alternative priority weight
Weight alternatives	0.503	0.25	0.224	0.022	
Supplier A	0.5172	0.272	0.151	0.353	0.370
Supplier B	0.1467	0.519	0.409	0.037	0.296
Supplier C	0.3358	0.156	0.219	0.304	0.264
Supplier D	0.0003	0.051	0.219	0.304	0.069

Table 10. Summary combination of priority weights: Sub-criteria of criterion C2.

Alternative	SC5	SC6	SC7	Alternative priority weight
Weight alternatives	0.471	0.057	0.471	
Supplier A	0.292	0.379	0.280	0.291
Supplier B	0.190	0.075	0.216	0.196
Supplier C	0.292	0.310	0.280	0.287
Supplier D	0.223	0.234	0.223	0.223

Table 11. Summary combination of priority weights: Sub-criteria of criterion C3.

Alternative	SC8	SC9	SC10	Alternative priority weight
Weight alternatives	0.451	0.225	0.324	
Supplier A	0.323	0.355	0.057	0.244
Supplier B	0.028	0.014	0.74	0.256
Supplier C	0.323	0.355	0.101	0.258
Supplier D	0.323	0.275	0.101	0.240

Supplier A ranked first as supplier, with a weight of 0.287. This was closely followed by Supplier C, with a weight of 0.285. Supplier B was the last supplier to be selected, with a weight of 0.197.

Table 12. Summary combination of priority weights: Sub-criteria of criterion C4.

Alternative	SC11	SC12	SC13	Alternative priority weight
Weight alternatives	0.053	0.434	0.512	
Supplier A	0.327	0.137	0.309	0.235
Supplier B	0.004	0.162	0.118	0.131
Supplier C	0.367	0.272	0.309	0.296
Supplier D	0.300	0.428	0.263	0.336

Table 13. Summary combination of priority weights: Main criteria of the overall objective.

Alternative	C1	C2	C3	C4	Alternative priority weight
Weight alternatives	0.102	0.669	0.046	0.183	
Supplier A	0.370	0.291	0.244	0.235	0.287
Supplier B	0.296	0.196	0.256	0.131	0.197
Supplier C	0.264	0.287	0.258	0.296	0.285
Supplier D	0.069	0.223	0.24	0.336	0.229

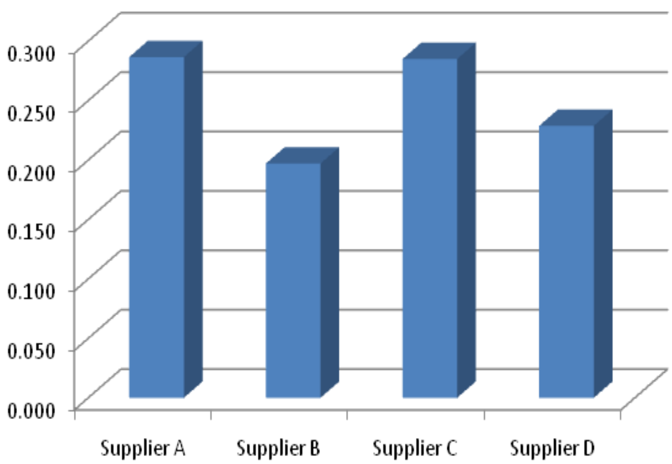

Figure 4. Final priority weights of each supplier.

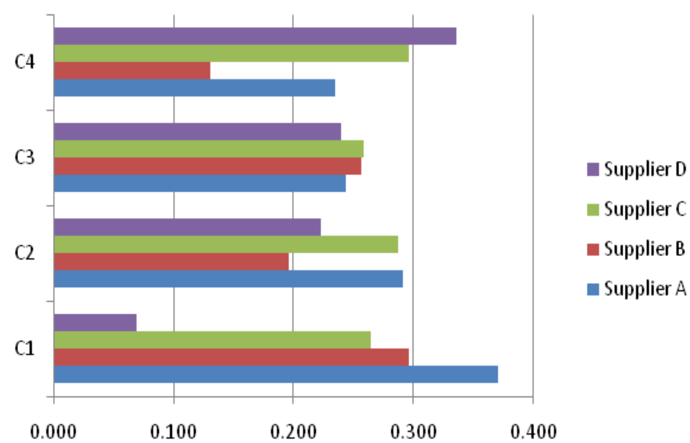

Figure 6. Sensitivity of each decision alternatives with respect to the criteria.

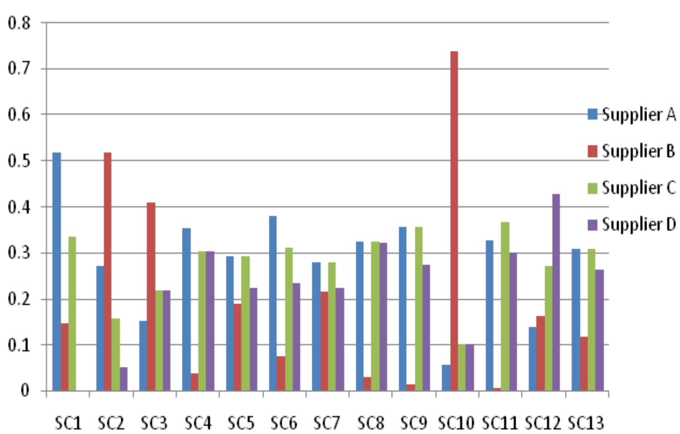

Figure 5. Sensitivity of each decision alternatives with respect to the sub-criteria.

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APPENDIX

Sample questions:

1) How important is criterion C1 when it is compared with criterion C2?

2) How important is criterion C1 when it is compared with criterion C3?

3) How important is sub-criterion SC1 when it is compared with SC2? and so on.