# FUZZY AHP–GOAL PROGRAMMING APPROACH FOR A SUPPLIER SELECTION PROBLEM

Berna Tektaş Sivrikaya*, Aycan Kaya**, Evren Dursun***
and Ferhan Çebi****

* Istanbul Technical University, Faculty of Management, Department of Management Engineering, Istanbul, Turkey, Email: tektasbe@ itu.edu.tr
** Istanbul Technical University, Faculty of Management, Department of Management Engineering, Istanbul, Turkey, Email: kayaayca@itu.edu.tr
*** Istanbul Technical University, Faculty of Management, Department of Management Engineering, Istanbul, Turkey, Email: dursun_e@yahoo.com
**** Istanbul Technical University, Faculty of Management, Department of Management Engineering, Istanbul, Turkey, Email: cebife@itu.edu.tr

**Abstract** This paper presents an integrated evaluation approach for decision support enabling effective supplier selection and ordering processes in textile industry. The integrated evaluation method in this study includes two phases that consist of fuzzy AHP and goal programming approaches. Supplier evaluation and selection is a multi-criterion decision problem which includes both qualitative and quantitative factors. That's why; firstly, linguistic variables expressed in trapezoidal fuzzy numbers are applied to assess weights and ratings of supplier selection criteria. Then a hierarchy multiple model based on fuzzy set theory is expressed and the geometric mean method of Buckley is used to aggregate pair wise comparisons. Finally, a goal programming model is built using the goals about coefficients of suppliers, total ordering cost, number of wrong deliveries, total delivery cost under the constraints of required minimum and maximum number of orderings and acceptable quality cost levels of each supplier and demand constraint of the product.

**Paper type: Research Paper**

**Published online:** 30 June 2015
Vol. 5, No. 3, pp. 271-285

ISSN 2083-4942 (Print)
ISSN 2083-4950 (Online)

***Keywords:*** *Supplier selection, fuzzy AHP, goal programming*

## 1. INTRODUCTION

Low labor cost is one of the key global competitiveness factors in textile industry. Inapproachable labor costs of Far East countries have been forcing textile companies to reengineer their business activities. Also, shortened product life cycles put pressure on companies to develop strategic partnerships with their suppliers in order to adapt quickly to a rapidly changing market (Huang & Keskar, 2007). Furthermore, due to changing escalation of competition and changing business conditions, textile and clothing industry is seeking to satisfy the increasing demand for healthier and more environmentally friendly products in international markets (Cebeci, 2009, p. 8900-8909). These situations enforce textile and apparel companies to reengineer their business activities. As a result of reengineering, over the last twenty years, de-integration, outsourcing and subcontracting have been increased in textile industry (Altinoz, Kilduff & Winchester, 2001).

As the organization becomes more and more dependent on their suppliers, the direct and indirect consequences of poor decision making will become more critical, and the global competitive environment drives organizations highly dependent on their suppliers (Chan & Kumar, 2007). Hence, in this study, we aimed to present a decision support model that enables effective supplier selection and ordering processes in textile industry.

Over the years, several techniques have been developed to solve the supplier selection problem efficiently. Analytic hierarchy process (AHP) (Bayraktar & Cebi, 2003; Chan, 2003, p. 3549-3579; Gencer & Gurpinar, 2007; Sen, Sen & Basligil, 2009) analytic network process (ANP), linear programming (LP) (Guneri, Yucel & Ayyildiz, 2009), multi-objective programming (Wang, Huang & Dismukes, 2004) data envelopment analysis (DEA) (Sevkli, Koh, Zaim, Demirbağ & Tatoğlu, 2007) neural networks (NN) (Kuo, Hong & Huang, 2010) and fuzzy set theory (FST) methods (Guneri, Yucel & Ayyildiz, 2009; Lee, Kang & Chang, 2009) have been applied in literature. Also, in the literature different methodologies have been integrated in order to take the advantages of various methods or complement weaknesses of these methods (Cakravista & Takahashi,2004; Guneri, Yucel & Ayyildiz, 2009; Kokangul & Susuz, 2009). Ghodsypour and O'Brien (1998) summarized a short but insightful overview of supplier selection research. de Boer et al. (2001) identified four research subjects within the research field of supplier selection: problem definition, formulation of criteria, prequalification and final selection. Basically, there are two kinds of supplier selection problem as multiple sourcing and single sourcing. In single sourcing, one supplier can satisfy all the buyer's needs and the management needs to make only one decision, which supplier is the best. Such as the case in this study, in multiple sourcing, no supplier can satisfy all the buyer's requirements, more than one supplier has to be selected (Ghodsypour & O'Brien, 1998). Besides, supplier selection is a multiple criteria decision-making (MCDM) problem affected by several conflicting factors such as price, quality and delivery.

Therefore, selecting the right suppliers which can maintain a continuous supply relationship requires a careful assessment because suppliers have varied strengths and weaknesses. Huang and Keskar (2007) listed the number and types of metrics proposed in the literature. Cost and quality have been the most dominant factors, along with on-time delivery and flexibility.

In practice, decision-making in supplier selection problem includes a high degree of fuzziness and uncertainties. Fuzzy set theory (FST) is one of the effective and widely used tools to handle uncertainty and vagueness (Bayrak, Celebi & Taskin, 2007; Chan, 2003, p. 3549-3579 ; Chen, Lin & Huang, 2006; Chen, Lin & Huang, 2006). In this paper, a fuzzy Analytical Hierarchy Process (FAHP) and linear goal programming (LGP) integrated multi-criteria decision making model has been developed to take into account both qualitative and quantitative factors in multiple sourcing supplier selection. Despite the convenience of AHP in handling both quantitative and qualitative criteria of multi-criteria decision making problems based on decision makers' judgments, in complex systems, the experiences and judgments of humans are represented by linguistic and vague patterns. So, fuzziness and vagueness exist in many decision-making problems. That's why we evaluate suppliers by using fuzzy AHP.

A number of methods have been developed to handle fuzzy comparison matrices in AHP. For example, Van Laarhoven and Pedrycz (1983) suggested a fuzzy logarithmic least squares method (LLSM) to obtain triangular fuzzy weights from a triangular fuzzy comparison matrix. Wang et al. (Wang, Elhag & Hua, 2006) presented a modified fuzzy LLSM. Buckley (1984) utilized the geometric mean method to calculate fuzzy weights. Chang (1996) proposed an extent analysis method, which derives crisp weights for fuzzy comparison matrices. In this study, Buckley's fuzzy AHP is used to find the fuzzy weights of the suppliers, since it is easy to implement and an efficient method (Buckley, Feuring & Hayashi, 2001, pp. 48-64). Linguistic values expressed in trapezoidal fuzzy numbers are used to assess weights and ratings of supplier selection criteria. The geometric mean method is used to aggregate pair wise comparisons. Also, in order to define order quantities assigned to each supplier, a linear goal programming model is built using maximizing total weights (scores) of suppliers and goals about minimizing total ordering cost, number of wrong deliveries, total delivery cost and under the minimum and maximum number of orderings from each supplier, quality cost and demand constraints.

The developed model has been applied in a regional agency of an international textile company who operates in garments industry and sells garments all over the world. This regional agency is in Istanbul, Turkey and outsources production of garments to the subcontractors. Therefore, the example company, in other words the regional agency in the study, has got a number of suppliers. In this study the proposed integrated FAHP-LGP model guides the decision maker in selecting most appropriate suppliers for the major products that have been supplied from multiple sources.

The rest of this paper is organized as follows. Section 2 explains the integrated FAHP-LGP model, a numerical example is given in section 3, and conclusions of the study are summed up in section 4.

## 2. THE INTEGRATED FAHP-LGP MODEL

The model presented in this paper applies the fuzzy AHP, which uses fuzzy pair-wise comparison matrices, to make the trade-off between tangible and intangible factors and calculate a rating of suppliers. By applying these ratings as coefficients of an objective function in LGP, the model can allocate order quantities among the favorable suppliers such that the manufacturing organization (customer) can choose the most favorable and least number of suppliers to achieve maximum efficiency. In order to develop the initial FAHP model, firstly, key supplier selections criteria have been deter-mined. Then, an initial hierarchical model including main criteria and sub-criteria has been constituted.

Level I of the FAHP model contains the goal of "supplier evaluation." The Level II contains main crite-ria such as "delivery capability", "quality of the product", "service capability" and "pricing policy" that influence supplier selection decisions. The main criteria are then divided into several sub-criteria at Level III as described below:

1. Delivery capability (DEL) (Guneri, Yucel & Ayyildiz, 2009;Sen, Sen & Basligil, 2009).

1.1. Conformance to delivery schedule (D1) (Chan & Kumar, 2007; Huang & Keskar, 2007; Kokangul & Susuz, 2009; Wang, Huang & Dismukes, 2004).

1.2. Conformance to quantity (D2) (Chan & Kumar, 2007; Huang & Keskar, 2007; Wang, Huang & Dismukes, 2004 ).

1.3. Choice of transportation (D3) (Chan & Kumar, 2007; Huang & Keskar, 2007; Wang, Huang & Dismukes, 2004).

2. Quality of the product (QUA) (Ghodsypour & O'Brien, 1998; Lee, Kang & Chang, 2009).

2.1. Performance about quality rejections before delivery (Q1) (Chan & Kumar, 2007; Kokangul & Susuz, 2009). As the textile materials are very delicate in nature, a slight variation in process parameters can cause significant deviation in product qualities which may ultimately result rejection. That's why the controller of the agent extracts samples of certain size from products. This quality control occurs at the supplier company. If samples fall outside pre-specified limits, all of the products are controlled. If important deficiencies exist the agent rejects the delivery of the product.

2.2. Performance about quality rejections after delivery (Q2) (Kokangul & Susuz, 2009): The agent takes products from supplier and exports them to another company in another country. If the importer company discovers that some product defects exist, it would reject the original delivery that had been discovered at that time. The payment tendered at the time of the original delivery is returned to the importer company.

3. Service capability (SER) (Chan & Kumar, 2007).

3.1. Flexibility (S1) (Chan & Kumar, 2007; Kokangul & Susuz, 2009)

3.2. Ease of communication (S4) (Chan & Kumar, 2007; Huang & Keskar, 2007; Wang, Huang & Dismukes, 2004).

3.3. Production facility and capacity (S3) (Chan & Kumar, 2007; Wang, Huang & Dismukes, 2004).

3.4. Response to Changes (S2) (Chan & Kumar, 2007; Huang & Keskar, 2007; Wang, Huang & Dismukes, 2004).

4. Pricing Policy (PRC)

4.1. Fair price (P1) (Chan & Kumar, 2007; Huang & Keskar, 2007; Wang, Huang & Dismukes, 2004).

4.2. Quantity discount rate (P2)

The pair-wise judgment starts from Level II and continues on to Level III. The relative importance of supplier evaluation criteria are determined by FAHP and a Buckley solution algorithm. Therefore, linguistic scales are defined with fuzzy sets.

A positive triangular fuzzy number can be defined as (l, m, u) and the membership function is defined as (Chan & Kumar, 2007; Lee, Kang & Chang, 2009).

$$\mu_{\tilde{n}}(x)=\begin{cases}0 & x<l,\\ \dfrac{(x-l)}{(m-l)} & l\le x\le m,\\ \dfrac{(u-x)}{(u-m)} & m\le x\le u,\\ 0 & x>u\end{cases} \qquad (1)$$

with $-\infty \le l \le m \le u \le \infty$ (Chan & Kumar, 2007; Lee, Kang & Chang, 2009).

The strongest grade of membership is parameter *m*, that is, $\mu_{\tilde{n}}(m)=1$, while *l* and *u* are the lower and upper bounds. Also a crisp number *k* can be expressed as a triangular number, (*k*, *k*, *k*). Moreover, a matrix $\tilde{C}$ is called as a fuzzy matrix if at least one element is a fuzzy number (Buckley, 1985, pp. 233-247).

The Buckley solution procedure can be summarized in equation (2) and (3) where $\tilde{C}_i$ is the pair-wise comparison matrix, and $\tilde{C}_m$ is the aggregated pair-wise comparison matrix (Cebi & Kahraman, 2010). The triangular fuzzy numbers are given by equation (4) for pair-wise comparison matrix where $\tilde{c}_{ij}$ the element of the pair-wise comparison matrix. If *i*th criterion is equal to *j*th criterion, $\tilde{c}_{ij}$ is equal to 1. If *i*th criterion is more important than to *j*th criterion, $\tilde{c}_{ij}$ takes the one of the values given in the first line of equation (4). Also, the linguistic evaluation scale, given in Table 1 can be used for triangular fuzzy numbers in Equation (3).

**Table 1** Characteristic function of the fuzzy numbers (Chan & Kumar, 2007)

| Scale of Fuzzy Number | | TFNs |
|---|---|---|
| Equally important | (Eq) | (1, 1, 1) |
| Weakly important | (Wk) | (2/3, 1, 3/2) |
| Essentially important | (Es) | (3/2, 2, 5/2) |
| Very strongly important | (Vs) | (5/2, 3, 7/2) |
| Absolutely important | (Ab) | (7/2, 4, 9/2) |

$$\tilde{C} = \left[\tilde{c}_{ij}\right] = \begin{bmatrix} \tilde{c}_{11} & \tilde{c}_{12} & \dots & \tilde{c}_{1n} \\ \tilde{c}_{21} & \tilde{c}_{22} & \dots & \tilde{c}_{2n} \\ . & . & \dots & . \\ . & . & \dots & . \\ \tilde{c}_{n1} & \tilde{c}_{n2} & \dots & \tilde{c}_{nn} \end{bmatrix} = \begin{bmatrix} 1 & \tilde{c}_{12} & \dots & \tilde{c}_{1n} \\ \tilde{c}_{21} & 1 & \dots & \tilde{c}_{2n} \\ . & . & \dots & . \\ . & . & 1 & . \\ \tilde{c}_{n1} & \tilde{c}_{n2} & \dots & 1 \end{bmatrix}, \text{ for } i, j = 1, 2, \dots, n \tag{2}$$

$$\tilde{C}_m = \sqrt[z]{\prod_{i=1}^{z} \tilde{C}_i} \tag{3}$$

Then, the fuzzy weight matrix is calculated by Buckley's Method as follows :

$$\tilde{c}_{ij} = \begin{cases} \text{if } i \text{ is more important than } j, & \text{assign one of } (2/3,1,3/2),(3/2,2,5/2),(5/2,3,7/2),(7/2,4,9/2) \\ \text{if } i \text{ and } j \text{ have the same importance, } 1 & \\ \text{if } i \text{ is less important than } j, & \text{assign one of } (2/3,1,3/2),(2/5,1/2,2/3),(2/7,1/3,2/5),(2/9,1/4,2/7) \end{cases} \tag{4}$$

$$\tilde{r}_i = \left(\tilde{c}_{i1} \otimes \tilde{c}_{i2} \otimes \dots \otimes \tilde{c}_{in}\right)^{1/n} \tag{5}$$

$$\tilde{w}_i = \tilde{r}_i \otimes \left(\tilde{r}_1 \otimes \tilde{r}_2 \otimes \dots \otimes \tilde{r}_n\right)^{-1} \tag{6}$$

where $\tilde{c}_{in}$ is the fuzzy comparison value of criterion *i* to criterion *n*, $\tilde{r}_i$ is the geometric mean of fuzzy comparison values, and $\tilde{w}_i$ is the fuzzy weight of supplier evaluation criteria *i*. The term $\tilde{w}_i$ denotes the relative importance of the evaluation criteria.

After the fuzzy relative weight matrix is obtained, a defuzzification process, which converts a fuzzy number into a crisp value, is utilized. Fuzzy numbers will be defuzzified into crisp values and then a normalization procedure will be applied. In this paper, a centroid method, which provides a crisp value based on the center of gravity, is used for the defuzzification process, since it is the most commonly used method Lee et al. (2009). Equation (7) presents both defuzzification and normalization procedure in one formula [8].

$$w_r = \frac{\tilde{w}_r}{\sum_{i=1}^{n} \tilde{w}_i} = \frac{w_{rl} + w_{rm} + w_{ru}}{\sum_{i=1}^{n} \tilde{w}_i} \tag{7}$$

where the importance of *r*th criterion, $w_r$, is a non-fuzzy number and n is the number of criteria.

The goal programming (GP) is an important technique to find a set of satisfying solutions to MCDM problems [22]. The purpose of GP is to minimize the unwanted deviations between the achievement of goals and their aspiration levels. GP can be expressed as follows (Lee, Kang & Chang, 2009; Liao & Kao, 2010; Ravindran, 2010):

$$\text{Min} \sum_{i=1}^{n} \left| f_i(X) - g_i \right| \text{ or Min} \sum_{i=1}^{n} d_i^+ + d_i^- \tag{8}$$

$$\text{s.t. } \underset{X \in F}{f_i(X)} - d_i^+ + d_i^- = g_i, \quad i = 1, 2, \ldots, n$$

where *F* is a feasible set, *X* is an element of F, $f_i(X)$ is the linear function of the *i*th goal, $g_i$ is the aspiration level of the *i*th goal, and $d_i^+$ and $d_i^-$ are the positive and negative deviation attached to the *i*th goal $\left| f_i(X) - g_i \right|$.

The decision variables and parameters of goal programming model are explained below.

Decision variables:

- $j$ supplier index, $j$ = 1, 2, 3, …, m
- $i$ index of goals, $j$ = 1, 2, 3, …, m
- $X_j$ purchasing quantity from supplier $j$
- $Y_j$ binary decision variable for the supplier $j$
- $g_i$ goal $i$, $i$ = 1, 2, 3, …., n
- $d_i^-$ amount of underachievement for goal $g_i$
- $d_i^+$ amount of overachievement for goal $Z^i$

Parameters:

- $c_j^p$ unit price of the supplier $j$ for the product (£/unit)
- $w_{supp\ j}$ FAHP score of the supplier $j$

$L_j$ minimum number of orderings for supplier $j$ (unit/season)
$U_j$ maximum number of orderings for supplier $j$ (unit/season)
$D$ minimum number of products that the agency has to send to the main company (unit)
$QC$ total quality control cost can be affordable by the local agency (₤)
$c_j^q$ quality control cost per product of each supplier (unit/₤)

## 3. THE CASE STUDY FOR EVALUATING SUBCONTRACTORS

In order to examine the practicality and the effectiveness of the proposed FAHP-LGP model for supplier evaluation, we use a regional agency of an international textile company that is located in Turkey. The main company of the agency operates in clothing industry and sells cloths all over the world, the local agency make negotiations with subcontractors in order to outsource cloth production and satisfy the product demand of the main company. As a result of these business activities, the local agency earns commission from both sides, from the main company and from the local textile company. Depending on the criterion used, one subcontracting clothing company may perform better than the others. Therefore, country manager of the agency, who is responsible from the negotiations with subcontractors, is interviewed first to decide the factors for selecting suppliers. Then, we define subcontractor selection problem and prepare a suppliers (subcontractors) candidate list by the help of the country manager of the company. With a comprehensive review of the literature, consultation with the country manager and consideration of data accessibility, the major factors (criteria) for selecting subcontractor companies are identified as delivery capability, quality of the product, service capability and pricing policy. Next, sub-criteria are identified. A questionnaire is prepared for the decision maker to compare criteria pair-wisely in their contribution toward achieving the goal of selecting the best subcontractor. The FAHP comparison matrices and the ratings of the suppliers are calculated by using Equation (2) – (7) and are shown in Table 2, 3, 4 and 5.

**Table 2** Evaluation results of the main criteria with respect to the overall goal

| | DEL | QUA | SER | PRC | $\tilde{w}_i$ | $w_r$ |
|---|---|---|---|---|---|---|
| **DEL** | (1, 1, 1) | (2/5, 1/2, 2/3) | (2/3, 1, 3/2) | (2/5, 1/2, 2/3) | (0.117, 0.179, 0.185) | 0.238 |
| **QUA** | (3/2, 2, 5/2) | (1, 1, 1) | (5/2, 3, 7/2) | (2/3, 1, 3/2) | (0.258, 0.396, 0.592) | 0.513 |
| **SER** | (2/3, 1, 3/2) | (2/7, 1/3, 2/5) | (1, 1, 1) | (2/7, 1/3, 2/5) | (0.099, 0.146, 0.218) | 0.191 |
| **PRC** | (2/5, 1/2, 2/3) | (2/3, 1, 3/2) | (5/2, 3, 7/2) | (1, 1, 1) | (0.185, 0.280, 0.425) | 0.058 |

Seven potential subcontractors of the regional agency are qualified to supply outsourced clothing that demanded by the main company.

**Table 3** Evaluation results of the sub-criteria regarding the main criteria

| | **D1** | **D2** | **D3** | $\tilde{w}_i$ | $w_r$ |
|---|---|---|---|---|---|
| **D1** | (1, 1, 1) | (2/5, 1/2, 2/3) | (2/3, 1, 3/2) | (0.165, 0.240, 0.361) | 0.246 |
| **D2** | (3/2, 2, 5/2) | (1, 1, 1) | (5/2, 3, 7/2) | (0.398, 0.550, 0.743) | 0.542 |
| **D3** | (2/3, 1, 3/2) | (2/7, 1/3, 2/5) | (1, 1, 1) | (0.147, 0.210, 0.304) | 0.212 |
| | **Q1** | **Q2** | | $\tilde{w}_i$ | $w_r$ |
| **Q1** | (1, 1, 1) | (2/7, 1/3, 2/5) | | (0.214, 0.250, 0.299) | 0.252 |
| **Q2** | (5/2, 3, 7/2) | (1, 1, 1) | | (0.632, 0.750, 0.884) | 0.748 |
| | **S1** | **S2** | **S3** | $\tilde{w}_i$ | $w_r$ |
| **S1** | (1, 1, 1) | (2/5, 1/2, 2/3) | (2/5, 1/2, 2/3) | (0.108, 0.170, 0.280) | 0.204 |
| **S2** | (3/2, 2, 5/2) | (1, 1, 1) | (2/3, 1, 3/2) | (0.209, 0.341, 0.542) | 0.400 |

**Table 4** Judgment results of the alternatives with respect to the sub-criteria

| | **SUPPLIERS** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ***D1*** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | $\tilde{w}_i$ | $w_r$ |
| **1** | (1,1,1) | (3/2,2,5/2) | (2/5,1/2,2/3) | (2/3,1,3/2) | (2/3,1,3/2) | (2/5,1/2,2/3) | (3/2,2,5/2) | (0.080,0.129,0.208) | 0.131 |
| **2** | (2/5,1/2,2/3) | (1,1,1) | (2/7,1/3,2/5) | (2/5,1/2,2/3) | (2/7,1/3,2/5) | (2/5,1/2,2/3) | (1,1,1) | (0.049,0.070,0.103) | 0.070 |
| **3** | (3/2,2,5/2) | (5/2,3,7/2) | (1,1,1) | (5/2,3,7/2) | (3/2,2,5/2) | (2/3,1,3/2) | (7/2,4,9/2) | (0.172,0.262,0.390) | 0.259 |
| **4** | (2/3,1,3/2) | (3/2,2,5/2) | (2/7,1/3,2/5) | (1,1,1) | (1,1,1) | (2/7,1/3,2/5) | (2/3,1,3/2) | (0.069,0.104,0.157) | 0.104 |
| **5** | (2/3,1,3/2) | (5/2,3,7/2) | (2/5,1/2,2/3) | (1,1,1) | (1,1,1) | (2/3,1,3/2) | (5/2,3,7/2) | (0.106,0.159,0.242) | 0.160 |
| **6** | (3/2,2,5/2) | (3/2,2,5/2) | (2/3,1,3/2) | (5/2,3,7/2) | (2/3,1,3/2) | (1,1,1) | (3/2,2,5/2) | (0.126,0.203,0.318) | 0.203 |
| **7** | (2/5,1/2,2/3) | (1,1,1) | (2/9,1/4,2/7) | (2/3,1,3/2) | (2/7,1/3,2/5) | (2/5,1/2,2/3) | (1,1,1) | (0.051,0.074,0.111) | 0.074 |
| ***D2*** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | $\tilde{w}_i$ | $w_r$ |
| **1** | (1,1,1) | (5/2,3,7/2) | (2/5,1/2,2/3) | (2/3,1,3/2) | (2/3,1,3/2) | (2/5,1/2,2/3) | (5/2,3,7/2) | (0.093,0.144,0.228) | 0.146 |
| **2** | (2/7,1/3,2/5) | (1,1,1) | (2/7,1/3,2/5) | (2/3,1,3/2) | (2/7,1/3,2/5) | (2/9,1/4,2/7) | (2/3,1,3/2) | (0.044,0.066,0.101) | 0.066 |
| **3** | (3/2,2,5/2) | (5/2,3,7/2) | (1,1,1) | (3/2,2,5/2) | (2/3,1,3/2) | (1,1,1) | (5/2,3,7/2) | (0.144,0.215,0.315) | 0.211 |
| **4** | (2/3,1,3/2) | (2/3,1,3/2) | (2/5,1/2,2/3) | (1,1,1) | (2/7,1/3,2/5) | (2/5,1/2,2/3) | (2/3,1,3/2) | (0.057,0.090,0.148) | 0.093 |
| **5** | (2/3,1,3/2) | (5/2,3,7/2) | (2/3,1,3/2) | (5/2,3,7/2) | (1,1,1) | (2/3,1,3/2) | (3/2,2,5/2) | (0.121,0.194,0.310) | 0.196 |
| **6** | (3/2,2,5/2) | (7/2,4,9/2) | (1,1,1) | (3/2,2,5/2) | (2/3,1,3/2) | (1,1,1) | (3/2,2,5/2) | (0.140,0.211,0.311) | 0.208 |
| **7** | (2/7,1/3,2/5) | (2/3,1,3/2) | (2/7,1/3,2/5) | (2/3,1,3/2) | (2/5,1/2,2/3) | (2/5,1/2,2/3) | (1,1,1) | (0.050,0.077,0.123) | 0.079 |
| **D3** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | $\tilde{w}_i$ | $w_r$ |
| **1** | (1,1,1) | (2/5,1/2,2/3) | (2/9,1/4,2/7) | (2/5,1/2,2/3) | (2/7,1/3,2/5) | (2/9,1/4,2/7) | (2/5,1/2,2/3) | (0.037,0.055,0.085) | 0.055 |
| **2** | (3/2,2,5/2) | (1,1,1) | (2/7,1/3,2/5) | (2/3,1,3/2) | (2/7,1/3,2/5) | (2/7,1/3,2/5) | (2/3,1,3/2) | (0.056,0.089,0.143) | 0.088 |
| **3** | (7/2,4,9/2) | (5/2,3,7/2) | (1,1,1) | (3/2,2,5/2) | (2/3,1,3/2) | (2/3,1,3/2) | (3/2,2,5/2) | (0.137,0.224,0.358) | 0.221 |
| **4** | (3/2,2,5/2) | (2/3,1,3/2) | (2/5,1/2,2/3) | (1,1,1) | (2/3,1,3/2) | (2/5,1/2,2/3) | (2/3,1,3/2) | (0.069,0.117,0.200) | 0.119 |
| **5** | (5/2,3,7/2) | (5/2,3,7/2) | (2/3,1,3/2) | (2/3,1,3/2) | (1,1,1) | (2/3,1,3/2) | (2/3,1,3/2) | (0.104,0.176,0.298) | 0.178 |
| **6** | (7/2,4,9/2) | (5/2,3,7/2) | (2/3,1,3/2) | (3/2,2,5/2) | (2/3,1,3/2) | (1,1,1) | (3/2,2,5/2) | (0.137,0.224,0.358) | 0.221 |
| **7** | (3/2,2,5/2) | (2/3,1,3/2) | (2/5,1/2,2/3) | (2/3,1,3/2) | (2/3,1,3/2) | (2/5,1/2,2/3) | (1,1,1) | (0.069,0.117,0.200) | 0.119 |

Suppliers can accept product order of the agency if it is between specific minimum and maximum amount limits because of their scale of economies and their capacity constraints. The upper and lower ordering limits are determined at the beginning of the season by mutual meetings between the supplier and the agency. The regional agency needs to purchase 3,128,000 units of product for this season. Minimum and maximum number of orderings can be acceptable by the suppliers are given in Table 6.

**Table 5** Supplier evaluation decision-making result

| $w_{supp1}$ | $w_{supp2}$ | $w_{supp3}$ | $w_{supp4}$ | $w_{supp5}$ | $w_{supp6}$ | $w_{supp7}$ |
|---|---|---|---|---|---|---|
| **0,135** | 0,089 | 0,232 | 0,096 | 0,119 | 0,233 | 0,097 |

**Table 6** Order limits for the suppliers

| | Order Limits of Supplier | |
|---|---|---|
| **Suppliers** | **Lower Ordering Limit ($L_i$)** | **Upper Ordering Limit ($U_i$)** |
| **1** | 1,440,000 | 36,000 |
| **2** | 960,000 | 60,000 |
| **3** | 1,800,000 | 120,000 |
| **4** | 600,000 | 30,000 |
| **5** | 360,000 | 24,000 |
| **6** | 650,000 | 18,000 |
| **7** | 1,000,000 | 12,000 |

Quality controllers of the agency visit the supplier every week at certain days. According to the types of the quality problems faced, the number of quality control visits in a week can be increased. Quality control cost of all of the suppliers is not wanted to exceed ₤ 13,000 by the regional agency. Quality control cost per product of each supplier is calculated in Table 7.

**Table 7** Quality control cost per product of each supplier

| Supplier | working days/week | Number of QCs | weeks/ season | Total number of QCs*weeks/ season | Number of product orderings | Quality control cost/ product $c_j^q$ |
|---|---|---|---|---|---|---|
| **1** | 5 | 1 | 12 | 60 | 1,440,000 | 0.00083 |
| **2** | 6 | 2 | 12 | 144 | 960,000 | 0.00300 |
| **3** | 6 | 2 | 12 | 144 | 1,800,000 | 0.00160 |
| **4** | 3 | 1 | 12 | 36 | 600,000 | 0.00120 |
| **5** | 4 | 2 | 12 | 96 | 360,000 | 0.00533 |
| **6** | 4 | 1 | 12 | 48 | 650,000 | 0.00148 |
| **7** | 5 | 2 | 12 | 120 | 1,000,000 | 0.00240 |

The agency wants to minimize its total purchasing cost. Average product cost, $c_i$ in ₤, for the same product group that can be purchased from supplier *i* is calculated according to the data of the previous seasons, and represented in Table 8.

**Table 8** The unit product price of each supplier

| | SUPPLIERS | | | | | | |
|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| $c_j^p$ | 5.04 | 5.01 | 5.03 | 5.05 | 5.04 | 5.03 | 5.01 |

Quality rejections cause extra cost to both supplier and the agency. That's why the second goal of the agency is minimizing total number of rejected products because of quality problems. Quality rejection percentages of each supplier at previous season are given in Table 9.

**Table 9** Quality control rejection percentages of each supplier according to the previous season

| Sup-plier | Number of deliveries/ season | Rejec-tions before delivery | % of rejections before delivery | Rejec-tion after delivery | % of rejections before delivery | Total number of rejections | % of total rejections ($r_j$) |
|---|---|---|---|---|---|---|---|
| **1** | 180 | 54 | 30.00% | 3 | 1.67% | 57 | 31.67% |
| **2** | 108 | 43 | 39.81% | 5 | 4.63% | 48 | 44.44% |
| **3** | 324 | 48 | 14.81% | 3 | 0.93% | 51 | 15.74% |
| **4** | 48 | 12 | 25.00% | 3 | 6.25% | 15 | 31.25% |
| **5** | 60 | 8 | 13.33% | 3 | 5.00% | 11 | 18.33% |
| **6** | 69 | 4 | 5.80% | 2 | 2.90% | 6 | 8.70% |
| **7** | 120 | 19 | 15.83% | 4 | 3.33% | 23 | 19.17% |

Third goal of the agency is maximizing total weighted AHP score (ratings) of suppliers (Table 5). The agency wants to minimize the number of products sent with aircraft. Percentages of products delivered with aircraft for each supplier is given in Table 10.

**Table 10** Percentages of products delivered with aircraft

| Sup-pliers | Number of products in deliveries with aircraft /season | % of products in aircraft deliveries $\left(d_j^a\right)$ | Number of products in deliveries with freight vessel | % of products in deliveries with vessel | Total number of products in deliveries | Freight cost of aircraft |
|---|---|---|---|---|---|---|
| **1** | 80,000 | 5,56% | 1,360,000 | 94,4% | 1,440,000 | 40,000.00 |
| **2** | 44,444 | 4,63% | 915,556 | 95,4% | 960,000 | 22,222.00 |
| **3** | 155,556 | 8,64% | 1,644,444 | 91,4% | 1,800,000 | 77,778.00 |
| **4** | 30,000 | 5,00% | 570,000 | 95,0% | 600,000 | 15,000.00 |
| **5** | 7,500 | 2,08% | 352,500 | 97,9% | 360,000 | 3,750.00 |
| **6** | 10,000 | 1,54% | 640,000 | 98,5% | 650,000 | 5,000.00 |
| **7** | 52,000 | 5,20% | 948,000 | 94,8% | 1,000,000 | 26,000.00 |

After the evaluation of suppliers by using FAHP, the LGP model for the supplier selection is set. The goals of the agency are minimizing purchasing cost ($G_1$), minimizing the number of rejected products because of quality problems ($G_2$), maximizing total weighted AHP score of suppliers ($G_3$), and minimizing the number of products sent with aircraft ($G_4$).

$$\text{Min } Z = P_1 d_1^+ + P_2 d_2^+ + P_3 d_3^- + P_4 d_4^+ \tag{16}$$

$$\text{s.t.} \quad X_j \geq LY_j \tag{17}$$

$$X_j \leq UY_j \tag{18}$$

$$\sum_{j=1}^{7} X_j \geq 3{,}128{,}000 \tag{19}$$

$$\sum_{j=1}^{7} c_j^q X_j \leq 13{,}000 \tag{20}$$

$$\sum_{j=1}^{7} c_j^p X_j + d_1^- - d_1^+ = 0 \quad \text{(Goal 1)} \tag{21}$$

$$\sum_{j=1}^{7} r_j X_j + d_2^- - d_2^+ = 0 \quad \text{(Goal 2)} \tag{22}$$

$$\sum_{j=1}^{7} w_{\text{supp}j} X_j + d_2^- - d_2^+ = 0 \quad \text{(Goal 3)} \tag{23}$$

$$\sum_{j=1}^{7} d_j^a X_j + d_2^- - d_2^+ = 0 \quad \text{(Goal 4)} \tag{24}$$

$$d_i^- \text{ x } d_i^+ = 0 \qquad i = 1,2,3,4 \tag{25}$$

$$d_i^- \geq 0 \qquad i = 1,2,3,4 \tag{26}$$

$$d_i^+ \geq 0 \qquad i = 1,2,3,4 \tag{27}$$

$$X_j \geq 0 \text{ and integer} \qquad j = 1,2,3,...,7 \tag{28}$$

$$Y_j \in \{0,1\} \qquad j = 1,2,3,...,7 \tag{29}$$

The objective is to minimize Z based on the goals selected and the weights obtained from FAHP. The constraints are explained as follows. Constraint (17) is the required minimum amount of orderings enables working with supplier *j*, and constraint (18) is limit of the amount of orderings because of the capacity allocated by supplier *j* to the agency. Equation (19) is the demand constraint about minimum number of required product, in other words, minimum number of products that the agency has to send to the main company by purchasing from its sub-contractors (suppliers). And also, the regional agency needs to purchase 3,128,000 units of product for this season. Constraint (20) is about the affordable total quality control cost. Quality controllers of the agency visit the supplier every week at certain days. According to the types of the quality problems faced because of the quality degradation in products of supplier *j*, number of the visiting days of quality controllers to that supplier changes. Quality control cost of all of the suppliers is not wanted to exceed ₤ 13,000 by the regional agency. Constraint (25) let the value of overachievement of goal *i* become zero, if underachievement of goal *i* has a positive value, or vice versa. Constraint (26), (27) and (28), let, respectively, the underachievement and overachievement of goal *I*, and the number of the products purchased, $X_j$, be a positive integer number. The decision variable $Y_j$ takes the value of 1, if any order is given to supplier *j*, otherwise it becomes 0. Constraint (29) let $Y_j$ be a binary number.

The MCGP model is solved using LINGO. According to these solutions the local agency should purchase 959,950 units from supplier 2, 518,050 units from supplier 3, 650,000 units from supplier 6, and 1,000,000 units from supplier 7.

## 4. CONCLUSION

Supplier selection and evaluation process is very complicated involving interrelationship among two or more organizations in a supply chain, and the process is multi-objective in nature. The selection of subcontractor companies is essential for local textile agencies that negotiate a transaction between the main and subcontractor companies. In this research, a multi criteria FAHP-LGP model is proposed to evaluate the performance of clothing companies and to allocate the purchase amount to the selected companies. Fuzzy AHP is applied first to obtain the weights of the criteria, and a GP approach is used to find the optimal solution of order allocation to suppliers.

## REFERENCES

Altinoz, C., Kilduff, P., Winchester Jr., S. C., 2001, “Current issues and methods in supplier selection”, Journal of Textile Institute, Vol. 92, No.2, pp. 128-141.

Bayrak, M. Y., Çelebi, N., Taskin, H.,2007, “A fuzzy approach method for supplier selection”, Production Planning and Control, Vol. 18, No.1, pp. 54-63.

Bayraktar, D., Cebi, F., 2003, “Supplier selection using analytical hierarchy process”, In Proceedings of PICMET’03. Portland, Oregon, USA, 20-24 July.

Buckley, J. J., 1985, Fuzzy hierarchical analysis, Fuzzy Sets and Systems, Vol. 17, pp. 233-247.

Buckley, J. J., Feuring, T.,Hayashi, Y., 2001, “Fuzzy hierarchical analysis revisited”, European Journal of Operational Research,Vol. 129, pp. 48-64.

Cakravastia, A.,Takahashi, K.,2004, “Integrated model for supplier selection and negotiation in a make-to-order environment”, International Journal of Production Research, Vol. 42, No.21, pp. 4457-4474.

Cebeci, U., 2009, “Fuzzy AHP-based decision support system for selecting ERP systems in textile industry by using balanced scorecard”, Expert Systems with Applications, Vol. 36, pp. 8900-8909.

Cebi, S., Kahraman, C., 2010, “Developing a group decision support system based on fuzzy information axiom”, Knowledge Based Systems, Vol. 23, pp. 3-6.

Chan, F. T. S.,2003, “Interactive selection model for supplier selection process: an analytical hierarchy process approach”, International Journal of Production Research, Vol. 4, No.15, pp.3549-3579.

Chan, F. T. S., Kumar, N., 2007, “Global supplier development considering risk factors using fuzzy extended AHP-based approach”, Omega: The International Journal of Management Science, Vol. 35, pp. 417-431.

Chang, D. Y., 1996, “Applications of the extent analysis method on fuzzy AHP”, European Journal of Operational Research, Vol. 95, pp. 649-655.

Chen, T. C., Lin, C. T., Huang, S. F., 2006, “A fuzzy approach for supplier evaluation and selection in supply chain management”, International Journal of Production Economics, Vol. 102, pp. 289-301.

de Boer, L., Labro, E., Morlacchi, P., 2001, A review of methods supporting supplier selection, European Journal of Purchasing & Supply Management, Vol. 7, pp. 75-89.

Ding, H., Benyoucef, L., Xie, X., 2005, “A simulation optimization methodology for supplier selection problem”, International Journal of Computer Integrated Manufacturing, Vol. 18, No. 2, pp. 210-224.

Gencer, C., Gurpinar, D., 2007, “Analytic network process in supplier selection: a case study in an electronic firm”, Applied Mathematical Modeling, Vol. 31, pp. 2475-2486.

Ghodsypour, S. H., O’Brien, C., 1998, “Decision support system for supplier selection using an integrated analytic hierarchy process and linear programming”, International Journal of Production Economics, Vol. 56, No.57, pp. 199-212.

Guneri, A. F., Yucel, A., Ayyildiz, G., 2009, “An integrated fuzzy-lp approach for a supplier selection problem in supply chain management”, Expert Systems with Applications, Vol.36, pp. 9223-9228.

Huang, S. H., Keskar, H., 2007, “Comprehensive and configurable metrics for supplier selection”, International Journal of Production Economics, Vol. 105, pp. 510-523.

Kokangul, A., Susuz, Z., 2009, “Integrated analytical hierarch process and mathematical programming to supplier selection problem with quantity discount”, Applied Mathematical Modeling, Vol. 33, pp. 1417-1429.

Kuo, R. J., Hong, S. Y., Huang, Y. C., 2010, “Integration of particle swarm optimization based-fuzzy neural network and artificial neural network for supplier selection”, Applied Mathematical Modeling, Vol. 34, pp. 3976-3990.

Lee, A. H. I., Kang, H. Y., Chang, C. T., 2009, “Fuzzy multiple goal programming applied to TFT-LCD supplier selection by downstream manufacturers”, Expert Systems with Applications, Vol. 36, pp. 6318-6325.

Liao, C. N., Kao, H. P., 2010, “Supplier selection model using Taguchi loss function analytical hierarchical process and multi-choice goal programming”, Computers and Industrial Engineering, Vol. 58, pp. 571-577.

Ravindran, A. R., Ufuk B., R. , Wadhwa, V., Yang, T., 2010, “Risk adjusted multicriteria supplier selection models with applications”, International Journal of Production Research, Vol. 48, No.2, pp. 405-424.

Sen, C. G., Sen, S., Basligil, H., 2009, “Pre-selection of suppliers through an integrated fuzzy analytic hierarchy process and max-min methodology”, International Journal of Production Research, Vol. 48, No. 6, pp. 1603-1625.

Sevkli, M.,2009, “An application of the fuzzy ELECTRE method for supplier selection”, International Journal of Production Research, Vol. 48, No. 12, pp. 3393-3405.

Sevkli, M., Koh, S. C. L., Zaim, S., Demirbağ, M., Tatoglu, E.,2007, An application of data envelopment analytic hierarchy process for supplier selection: a case study of BEKO in Turkey, International Journal of Production Research, Vol. 45, No. 9, pp. 1973-2003.

van Laarhoven, P. J. M., Pedrycz, M., 1983, “A fuzzy extension of Saaty’s priority theory, Fuzzy Sets and Systems”, Vol. 11, No:1-3, pp. 229–241.

Wang, Y. M., Elhag, T. M. S., Hua, Z. S., 2006, "A modified fuzzy logarithmic least squares method for fuzzy analytic hierarchy process", Fuzzy Sets and Systems, Vol.157, pp. 3055–3071.

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

## BIOGRAPHICAL NOTES

**Berna Tektas Sivrikaya** received her MSc in Management Engineering at the Istanbul Technical University (ITU) in 2002. She earned her BSc in Management Engineering at the Istanbul Technical University, Istanbul in 2005. She worked at Istanbul Technical University as a Research Assistant in operational research area until January 2014. Previously, she had worked as a product manager in 2007, and worked as a brand manager in 2006 in different companies. Her research interests are electricity markets, operations research, operations management, mathematical programming, heuristic design and optimization, pricing and quality of service in telecommunication networks.

**Aycan Kaya** is a research assistant at ITU Management Engineering Department. She received her BSc in Industrial Engineering at Gazi University, Ankara in 2008 and she declared her double major at Electrical and Electronics Engineering at Gazi University in 2009. She received her MSc in Industrial Engineering at TOBB University of Economics & Technology in 2014. Now, she is doing PhD in Industrial Engineering at ITU. Her research interests are supply chain management and operations research.

**Evren Dursun** is a garment technologist at Memo Fashions Ltd in UK. He received his BSc in Textile Sciences and Engineering at ITU in 2003 and then received his MSc in Management Engineering at ITU in 2009.

**Ferhan Çebi** is a Professor at ITU Management Engineering Department. Her research interests are quantitave decision techniques, operations research, production systems analysis and mathematical programming. Her papers appear in numerous journal including International Journal of Computational Intelligence Systems, Journal of Multiple-Valued Logic and Soft Computing, etc.