

## Supplier selection problem: A fuzzy multicriteria approach

A.M. Allouche & T. Jouili

### ABSTRACT

The purpose of this paper is to suggest a fuzzy multi-criteria approach to solve the supplier selection problem, an approach based on the fuzzy analytic hierarchy process and imprecise goal programming. To deal with decision-maker (DM) preferences, the concept of satisfaction function is introduced. The proposed approach is applied to a real case, a Tunisian company, in which the DM considers several conflicting objectives simultaneously: maximising the total value of purchases, minimising the total cost of the product, minimising the total number of defective products and minimising the total number of units delivered late. Using a multi-objective mathematical model and LINDO software, the results show that the proposed approach is very useful for selecting the best supplier and fulfilling DM preferences.

**Keywords:** Supplier selection, multi-criteria decision-making, fuzzy logic, satisfaction function, imprecise goal programming (IGP), fuzzy analytic hierarchy process (FAHP).

### Introduction

Supplier selection is considered to be a complex multi-criteria decision-making problem in most manufacturing firms. Thus, companies take care in selecting the right suppliers. According to Tadeusz (2010), the supplier selection problem includes both qualitative and quantitative factors, and it is necessary to make a trade-off between them to select the best suppliers.

Recently, different methods and approaches have been put forward for this kind of problem. Ordoobadi (2009) and Ishizaka (2014) consider two factors to rank all

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selection methods: (a) the supplier performance on decision criteria and (b) the relative weight of these criteria. In fact, in the literature, the two most important aspects of the supplier selection process are: (a) the selected criteria and (b) the choice of a method to rank the available suppliers.

In this paper, to support the decision-maker (DM) in selecting the best suppliers, a fuzzy multi-criteria approach based on the fuzzy analytic hierarchy process (FAHP) and imprecise goal programming (IGP) with satisfaction function to define the optimal quantities between them is proposed. In this context, two steps will be considered: evaluation and shipment. Determining a set of criteria and weight using FAHP is done in the first step, and in the second step, we propose a multi-objective mathematical model to determine the suppliers' optimal order quantities.

This paper is divided into three sections. Existing studies on supplier selection in the literature are summarised in section 1. Section 2 contains a description of a new approach based on FAHP and the IGP with satisfaction concepts. In section 3 a case study is proposed based on the two above techniques. Finally, the authors conclude with a summary and suggestions for future research.

## Literature review

Deemed as a multi-criteria decision-making problem, the supplier selection process receives considerable attention in the literature. The multifaceted nature of the problem was first recognised by Dickson (1966), who examined the importance of supplier evaluation criteria. Therefore, the criteria most identified are quality, cost and delivery performance history. Several techniques and models are used to solve these kinds of problems. They are classified as individual and integrated approaches (Ho et al. 2010).

The individual techniques are data envelopment analysis (DEA) (Saen & Zohrehbandian 2008; Zohrehbandian & Saen 2010), mathematical programming (Arunkumar et al. 2008), fuzzy set theory (Aydin Keskin et al. 2010), analytic hierarchy process (AHP) (Kilinceci & Onal 2011; Arunkumar et al. 2011), analytic network process (ANP) (Sarkis & Talluri 2002; Gencer & Gürpınar 2007).

For integrated techniques integrated AHP and goal programming (GP) (Perçin 2006), integrated AHP and fuzzy linear programming (Kumar et al. 2008), integrated ANP and multi-objective programming (Demirtas & Üstün 2008), integrated ANP and DEA (Hasan et al. 2008) and integrated ANP and GP (Demirtas & Üstün 2009) are mentioned.

Other techniques and approaches are proposed. Wang et al. (2005) integrated AHP and pre-emptive goal programming to develop a multi-criteria decision-making methodology for supplier selection. Lee et al. (2009) applied fuzzy goal

programming to propose a model to enhance selecting Thin Film Transistor Liquid Crystal Display (TFT-LCD) suppliers. Liao and Kao (2011) combined a multi-choice goal programming approach and fuzzy techniques to help the manager set the aspiration levels attached to each objective for supplier selection problems.

In order to help the manager/DM to choose the best supplier, Ishizaka (2014) compares the following methods: fuzzy logic, AHP, FAHP and hybrid fuzzy AHP.

Based on the idea that the supplier problem is considered as one activity among many supply chain problems, Azimian and Aouni (2017) propose chance-constrained programming and the satisfaction function concept to formulate strategic and tactical decisions within the supply chain, while demand, supply and total cost are random variables. Ku et al. (2010) propose a new approach to global supplier selection to elucidate weights for each goal of global supplier selection with different supply chain strategies through a combination of FAHP and fuzzy GP and the integration of multi-managers' opinions into the model.

The literature review shows that numerous studies did not take into account the DM's preferences. In this paper, the concept of satisfaction functions will be utilised to integrate explicitly the DM's preferences according to the deviations between the achievement and the aspiration levels of the following criteria: the total value of purchases, the total cost of the product, percentage of defective products and percentage of items delivered late.

## Proposed approach

Many conflicting objectives characterise the problem of supplier selection. The maximisation of the purchase value, the minimisation of cost and delay in delivery and the maximisation of the profit are the most identified. The buyer or the DM strives for a satisfying compromise among the set of the considered objectives. The authors used IGP with the satisfaction functions to integrate explicitly the DM's preferences in the supplier selection process.

In this context, an integrated method based on two steps is proposed. In the first step (evaluation), the FAHP method is used to determine the weights of the suppliers. In the second step (shipment), the IGP with satisfaction function is used to determine the quantity purchased from the supplier selected.

## Evaluation step

To evaluate suppliers and obtain a global ranking, a well-known method for solving decision-making problems called FAHP, which is based on the concept of fuzzy set theory, introduced by Zadeh (1965), is used. FAHP was first introduced in 1983

by Van Laarhoven and Pedrycz. It is similar to the traditional AHP, except that the verbal appreciation is converted into a numerical scale. Taylor (2004) defines AHP as a method of ranking decision alternatives and selecting the best one when the DM has multiple criteria. One of the latest approaches to solution processes of FAHP methodology is based on Chang's extent analysis (1996). The theoretical fundamentals of Chang's extent analysis are defined in four steps (Erensal et al. 2006; Kahraman et al. 2004) in literature.

Using the following fuzzy comparison matrices:

$$\tilde{A} = \begin{pmatrix} \tilde{a}_{11} & \cdot & \cdot & \tilde{a}_{1n} \\ \tilde{a}_{21} & \cdot & \cdot & \tilde{a}_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ \tilde{a}_{n1} & \cdot & \cdot & \tilde{a}_{nn} \end{pmatrix} \quad \text{with } \tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij}) \quad \text{Eq.1}$$

All pairwise comparison judgements are represented by fuzzy triangular numbers  $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$  where  $i = j = 1, 2, \dots, n$ . It is assumed that  $l_j < m_j < u_j$  when  $i \neq j$  otherwise,  $\tilde{a}_{ij} = \tilde{a}_{ji} = (1, 1, 1)$ . Note that the parameters  $l$ ,  $m$  and  $u$  denote the smallest possible value, the most promising value and the largest possible value, respectively, that describe a fuzzy event (Javanbarg et al. 2012)).

**Step 1:** Obtain the sum of each line by using the following relation:

$$LS_i = \sum_{j=1}^n \tilde{a}_{ij} = \left( \sum_{j=1}^n l_{ij}; \sum_{j=1}^n m_{ij}; \sum_{j=1}^n u_{ij} \right) \quad \text{Eq.2}$$

**Step 2:** Normalise the sum  $S_i = \sum_{j=1}^n \tilde{a}_{ij} \times \left| \sum_{i=1}^n \sum_{j=1}^n \tilde{a}_{ij} \right|^{-1}$  Eq.3

$$\text{with: } \left| \sum_{i=1}^n \sum_{j=1}^n \tilde{a}_{ij} \right|^{-1} = \left( \frac{1}{\sum_{i=1}^n u_{ij}}, \frac{1}{\sum_{i=1}^n m_{ij}}, \frac{1}{\sum_{i=1}^n l_{ij}} \right) \quad \text{Eq.4}$$

**Step 3:** The degree of possibility of  $S_i = (l_i, m_i, u_i) \geq S_j = (l_j, m_j, u_j)$  (Fig.1) is defined as follows:  $V(S_i \geq S_j) = \sup_{y \geq x} \left[ \min(\mu_{S_j}(x), \mu_{S_i}(y)) \right]$

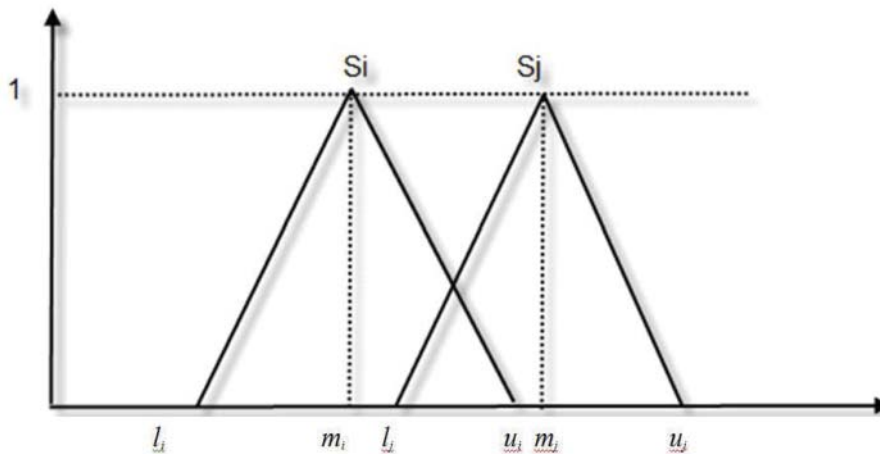
Note that  $x$  and  $y$  are the axis of membership function of each criterion. This expression can be written differently as follows:

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$$V(S_i \geq S_j) = \begin{cases} 1 & \text{if } m_i \geq m_j \\ 0 & \text{if } l_j \geq l_i \\ \frac{l_j - u_i}{(m_i - u_i) - (m_j - l_j)} & \text{otherwise} \end{cases} \quad \text{Eq.5}$$

**Step 4:** Assume that  $d'(A_i) = \min V(S_i \geq S_j)$  for  $j=1,2,\dots,n$ ; and  $j \neq i$

The weight vector  $W' = (d'(A_1), d'(A_2), \dots, d'(A_n))$  and via normalisation, we obtain the following normalised weight vectors  $W = (w_1, w_2, \dots, w_n)^T$



**Figure 1:** Degree of possibility

### Shipment step

To determine the number of orders from each supplier, a multi-objective linear programming model based on the IGP model is proposed. To explicitly take into account the DM's preferences, the satisfaction function concepts are used.

#### Decision variables and parameters of the model

$x_i$  = quantity purchased from the supplier  $i$

$$y_i = \begin{cases} 1, & \text{if supplier } (i) \text{ is chosen} \\ 0, & \text{otherwise} \end{cases}$$

- $D$  = demand for product
- $w_i$  = overall score of supplier  $j$  obtained by FAHP model
- $p_i$  = purchase price of the product from supplier  $i$
- $t_i$  = percentage of items delivered late from supplier  $i$
- $q_i$  = percentage of defective products delivered from supplier  $i$
- $C_i$  = capacity of supplier  $i$

**Functions of objectives**

Maximise total value of purchases:  $Max Z_1 = \sum_{i=1}^n w_i x_i$  Eq.6

Minimise total purchase cost of product:  $Min Z_2 = \sum_{i=1}^n p_i x_i$  Eq.7

Minimise total number of defective products:  $Min Z_3 = \sum_{i=1}^n q_i x_i$  Eq.8

Minimise total number of units delivered late:  $Min Z_4 = \sum_{i=1}^n t_i x_i$  Eq.9

**Constraints**

Demand:  $\sum_{i=1}^n x_i = D$  means that the sum of assigned order quantities to  $i$  suppliers should meet the buyer's demand.

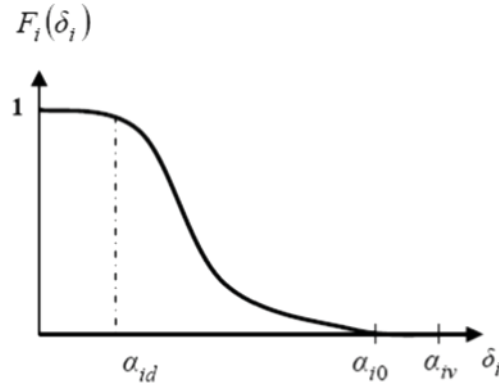
Capacity:  $x_i \leq C_i y_i \quad \forall i = 1, 2, \dots, n$

Non-negativity:  $x_i \geq 0 \quad \forall i = 1, 2, \dots, n$

**IGP with satisfaction functions**

Introduced by Charnes and Cooper in 1961, GP is considered an important technique to find a satisfying solution to multi-criteria decision-making problems. In the literature, various techniques such as weighted goal programming (WGP), MinMax GP and lexicographic GP are found. To reflect the DM preferences in the decision process, Martel and Aouni (1990, 1996) introduced the concept of the satisfaction functions (Allouche et al. 2009). In its general form, the satisfaction function is presented as follows:

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**Figure 2:** General form of satisfaction function

Consider:

$F_i(\delta_i)$  : the value of satisfaction function associated with deviation  $\delta_i$

$\alpha_{id}$  : indifference threshold

$\alpha_{io}$  : nil satisfaction threshold

$\alpha_{iv}$  : veto threshold

When the deviation  $\delta_i$  is within  $[0, \delta_{id}]$  the DM is fulfilled and satisfaction level is at its maximum value of 1. If the deviation  $\delta_i$  is within  $[\delta_{id}, \delta_{iv}]$ , the DM's satisfaction function is decreasing monotonously. Moreover, all solutions with deviations that exceed the veto threshold  $\delta_{iv}$  (Aouadni et al. 2013) are rejected.

To take into account the imprecision of values, the authors suppose that the goals' value,  $\xi_i$  instead of  $g_i$  to characterise their imprecise and fuzzy nature, can be any point on a given target interval,  $\varepsilon_i \in [g_i^L, g_i^U]$  where the upper and lower limits are set by the DM.

The following mathematical model is based on IGP with satisfaction function and combined with FAHP. It allows us to explicitly incorporate the DM's preferences in the selection process.

$$Max \ Z = w_1^- F_1^-(\delta_1^-) + w_2^+ F_2^+(\delta_2^+) + w_3^+ F_3^+(\delta_3^+) + w_4^+ F_4^+(\delta_4^+) \quad Eq.10$$

Subject to:

$$\sum_{i=1}^n w_i x_i + \delta_1^- - \delta_1^+ = \varepsilon_1$$

$$\sum_{i=1}^n p_i x_i + \delta_2^- - \delta_2^+ = \varepsilon_2$$

$$\sum_{i=1}^n q_i x_i + \delta_3^- - \delta_3^+ = \varepsilon_3$$

$$\sum_{i=1}^n t_i x_i + \delta_4^- - \delta_4^+ = \varepsilon_4$$

$$\sum_{i=1}^n x_i = D$$

$$x_i \leq C_i y_i$$

$$x_i \geq 0, \delta_1^-, \delta_2^+, \delta_3^+ \text{ and } \delta_4^+ \geq 0$$

Where:

$F_i^+(\delta_i^+)$  and  $F_i^-(\delta_i^-)$  = DM's satisfaction function associated with the positive and negative deviations, respectively

$w_i^+$  and  $w_i^-$  = important coefficients associated with the positive and negative deviations, compared to the values of goals

$\delta_j^+$  and  $\delta_j^-$  = positive and negative deviations from the  $j^{\text{th}}$  goal

$\varepsilon_i$  = goal values are defined on the interval  $\left( \varepsilon_i = \frac{(g_i^L + g_i^U)}{2} \right)$

## Case study

The approach proposed in the previous section is now applied to a real case study on supplier selection in order to obtain an illustrative result. The case study concerns a Tunisian company specialising in commercialised computer and office materials. The objective of the purchasing department of this company is to choose the best suppliers and assign their optimum order quantities while maximising the satisfaction level of the DM. In its commercial philosophy, the company selects the best supplier from the following supplier set: A, B, C, D and E, all based on the criteria of price ( $C_1$ ), quality ( $C_2$ ), geographical location ( $C_3$ ), flexibility ( $C_4$ ), delivery ( $C_5$ ) and after-sales service ( $C_6$ ).



### Evaluation step

Using the Saaty scale (1-9) presented by Saaty (1996), the company built a linguistic evaluation of the set of criteria. This linguistic evaluation is then transformed into a pairwise comparison as presented in Table 1. For example,  $C_1/C_5=5$  means that criterion 1 (price) is 5 times more important than criterion 5 (delivery) and in its fuzzy form we obtain (4,5,6).

As mentioned in section 2, the evaluation step is composed of four steps. Firstly, we need to calculate the sum of each line. For example:  $LS_1 = (13, 16, 19)$ ,  $LS_2 = (17, 20, 23)$ ,  $LS_3 = (6.291; 8,342; 10,417)$ , ...,  $LS_6 = (2,875; 3,142; 3,666)$ . After having normalised the sum in the second step,  $S_1 = (0,1716; 0,248; 0,3515)$ ,  $S_2 = (0,2244; 0,31; 0,4255)$ ,  $S_3 = (0,083; 0,1293; 0,1927)$ , ...,  $S_6 = (0,0379; 0,0487; 0,0678)$  is obtained. Then, the sum of  $l_i$ ,  $m_i$ , and  $u_i$  are 53,957; 64,494 and 75,49, respectively. The value of

$$\left( \frac{1}{\sum_{i=1}^n u_{ij}}, \frac{1}{\sum_{i=1}^n m_{ij}}, \frac{1}{\sum_{i=1}^n l_{ij}} \right) = \left( \frac{1}{75,49}, \frac{1}{64,494}, \frac{1}{53,957} \right) = (0,0132; 0,0155; 0,0185)$$

In the third step, the degree of possibility of  $S_i(l_i, m_i, u_i) \geq S_j(l_j, m_j, u_j)$  is calculated as follows:

$$V(S_1 \geq S_2, S_3, S_4, S_5, S_6) = \min(0, 1, 1, 1, 1) = 0; \quad V(S_2 \geq S_1, S_3, S_4, S_5, S_6) = \min(1, 1, 1, 1, 1) = 1$$

$$V(S_3 \geq S_1, S_2, S_4, S_5, S_6) = \min(0, 0, 0, 1, 1) = 0; \quad V(S_4 \geq S_1, S_2, S_3, S_5, S_6) = \min(1, 0, 1, 1, 1) = 0$$

$$V(S_5 \geq S_1, S_2, S_3, S_4, S_6) = \min(0, 0, 0, 0, 1) = 0; \quad V(S_6 \geq S_1, S_2, S_3, S_4, S_5) = \min(0, 0, 0, 0, 1) = 0$$

In the fourth step, the weight vector is obtained as follows:

$$W' = (0, 1, 0, 0, 0, 0)^T = (0, 1, 0, 0, 0, 0)$$

**Table 1:** Importance degree of criteria

	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	C <sub>4</sub>	C <sub>5</sub>	C <sub>6</sub>	Weights
C <sub>1</sub>	(1,1,1)	(1,1,1)	(4,5,6)	(1,1,1)	(4,5,6)	(2,3,4)	0
C <sub>2</sub>	(1,1,1)	(1,1,1)	(6,7,8)	(1,1,1)	(6,7,8)	(2,3,4)	1
C <sub>3</sub>	$\left(\frac{1}{6}, \frac{1}{5}, \frac{1}{4}\right)$	$\left(\frac{1}{8}, \frac{1}{7}, \frac{1}{6}\right)$	(1,1,1)	(2,3,4)	(1,1,1)	(2,3,4)	0
C <sub>4</sub>	(1,1,1)	(1,1,1)	$\left(\frac{1}{4}, \frac{1}{3}, \frac{1}{2}\right)$	(1,1,1)	(2,3,4)	(6,7,8)	0
C <sub>5</sub>	$\left(\frac{1}{6}, \frac{1}{5}, \frac{1}{4}\right)$	$\left(\frac{1}{8}, \frac{1}{7}, \frac{1}{6}\right)$	(1,1,1)	$\left(\frac{1}{4}, \frac{1}{3}, \frac{1}{2}\right)$	(1,1,1)	(1,1,1)	0
C <sub>6</sub>	$\left(\frac{1}{4}, \frac{1}{3}, \frac{1}{2}\right)$	$\left(\frac{1}{4}, \frac{1}{3}, \frac{1}{2}\right)$	$\left(\frac{1}{4}, \frac{1}{3}, \frac{1}{2}\right)$	$\left(\frac{1}{8}, \frac{1}{7}, \frac{1}{6}\right)$	(1,1,1)	(1,1,1)	0

Suppliers are then compared based on the set of criteria. The pairwise comparison matrix of suppliers according to the second criterion (quality) is presented in Table2. As before, the sum of each line is calculated. For example:  $LS_1 = (9, 13, 17)$ ,  $LS_2 = (6,25, 9,33, 12,5), \dots, LS_5 = (3,91; 5,333; 7,5)$ . After having normalised the sum in the second step, the following was obtained:  $S_1 = (0,181; 0,386; 0,636), \dots, S_5 = (0,079; 0,158; 0,28)$ . Then, the sum of  $l_i, m_i,$  and  $u_i$  are 26,749; 33,648 and 49,666, respectively.

**Table 2:** Fuzzy pairwise comparison of suppliers V's quality

Quality	A	B	C	D	E
A	(1,1,1)	(2,3,4)	(3,4,5)	(2,3,4)	(1,2,3)
B	$\left(\frac{1}{4}, \frac{1}{3}, \frac{1}{2}\right)$	(1,1,1)	(3,4,5)	(1,2,3)	(1,2,3)
C	$\left(\frac{1}{5}, \frac{1}{4}, \frac{1}{3}\right)$	$\left(\frac{1}{5}, \frac{1}{4}, \frac{1}{3}\right)$	(1,1,1)	$\left(\frac{1}{4}, \frac{1}{3}, \frac{1}{2}\right)$	$\left(\frac{1}{4}, \frac{1}{3}, \frac{1}{2}\right)$
D	$\left(\frac{1}{4}, \frac{1}{3}, \frac{1}{2}\right)$	$\left(\frac{1}{3}, \frac{1}{2}, 1\right)$	(2,3,4)	(1,1,1)	(2,3,4)
E	$\left(\frac{1}{3}, \frac{1}{2}, 1\right)$	$\left(\frac{1}{3}, \frac{1}{2}, 1\right)$	(2,3,4)	$\left(\frac{1}{4}, \frac{1}{3}, \frac{1}{2}\right)$	(1,1,1)

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The value of:

$$\left( \frac{1}{\sum_{i=1}^n u_{ij}}, \frac{1}{\sum_{i=1}^n m_{ij}}, \frac{1}{\sum_{i=1}^n l_{ij}} \right) = \left( \frac{1}{49,666}, \frac{1}{33,648}, \frac{1}{26,749} \right) = (0,02; 0,03; 0,037)$$

In the third step, the degree of possibility of  $S_i(l_i, m_i, u_i) \geq S_j(l_j, m_j, u_j)$  is calculated as follows:

$$\begin{aligned} V(S_1 \geq S_2, S_3, S_4, S_5) &= \min(1, 1, 1, 1) = 1; V(S_2 \geq S_1, S_3, S_4, S_5) = \min(0, 1, 1, 1) = 0 \\ V(S_3 \geq S_1, S_2, S_4, S_5) &= \min(0, 0, 0, 0) = 0; V(S_4 \geq S_1, S_2, S_3, S_5) = \min(0, 0, 1; 0, 972) = 0 \\ V(S_5 \geq S_1, S_2, S_3, S_4) &= \min(0, 0, 1, 1) = 0; \end{aligned}$$

In the fourth step, the weight vector is obtained as follows:

$$W' = (1, 0, 0, 0, 0)^T = (1, 0, 0, 0, 0)$$

Doing the same with the other five criteria, the obtained global score of the suppliers is shown in Table 3.

**Figure 3:** Degree of relative importance of suppliers with regard to criteria

	C <sub>1</sub> (0)	C <sub>2</sub> (1)	C <sub>3</sub> 0	C <sub>4</sub> 0	C <sub>5</sub> 0	C <sub>6</sub> 0	Final score
A	1	1	0,2	1	1	1	<b>1</b>
B	0	0	0,2	0	0	0	<b>0</b>
C	0	0	0,2	0	0	0	<b>0</b>
D	0	0	0,2	0	0	0	<b>0</b>
E	0	0	0,2	0	0	0	<b>0</b>

Based on the final score obtained and shown in Table 3, the final priorities of suppliers A, B, C, D and E are equal to 1,0,0,0,0 and 0, respectively. Hence, the greatest priority goes to supplier A. However, its production capacity does not meet the demand, and therefore the concept of satisfaction function is needed.

### Shipping step

In this step, the authors have to distribute the number of orders between the suppliers using several satisfaction functions and the mathematical model based on IGP presented in 2.2. Tables 4 and 5 reveal all data needed by the company.

Generally, the DM was asked to identify the level which he/she considered totally satisfying or dissatisfying (Aouadni et al. 2013). The related satisfaction function at the first or second objective is shown in Figure 3. Note that for the others, it is easy to obtain their shape according to the thresholds mentioned in Table 5.

**Table 4:** Collected data

	A	B	C	D	E
Price (1000\$)	0,23	0.266	0.227	0.247	0.223
Capacity (units)	1000	500	700	350	400
% of products delivered late	5%	3%	4%	3%	15%
% of defective products	0,33%	0,22%	0,32%	0,21%	0,11%
Total demand	$\square D \in [D_L, D_U] = [1500, 2500]$				

**Table 5:** Data set for satisfaction function

	Units	$w_i$	$g_j^L$	$g_j^U$	$g_j$	thresholds	
Obj1: total value of purchases	units	0.2	700	1300	1000	$\alpha_{10} = 50$	$\alpha_{1v} = 150$
Obj2: total cost of purchases	1000\$	0,5	300	700	500	$\alpha_{20} = 150$	$\alpha_{2v} = 200$
Obj3: total rate of defective products	units	0,15	40	100	70	$\alpha_{30} = 5$	$\alpha_{3v} = 10$
Obj4: total rate of products delivered late	units	0,15	2	8	5	$\alpha_{40} = 2$	$\alpha_{4v} = 4$

Fig. 3(a)

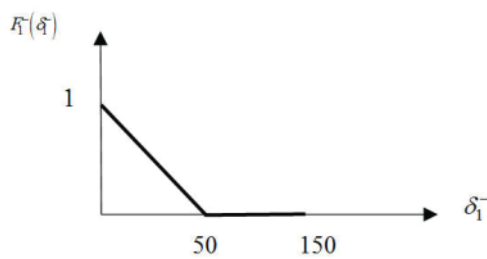
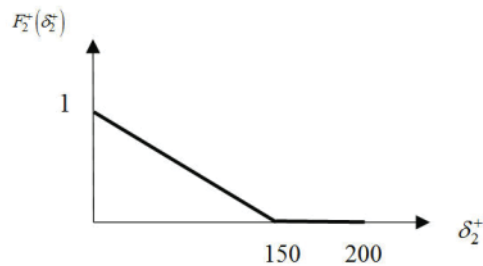


Fig. 3(b)



**Figure 3:** Satisfaction function related to the first and second objectives

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The satisfaction function of the first objective can be explained as follows:

$$F_1^-(\delta_1^-) = \begin{cases} f_1(\delta_1^-) = 1 - \frac{1}{50}\delta_1^- & \text{if } 0 \leq \delta_1^- \leq 50 \\ f_2(\delta_1^-) = 0 & \text{Otherwise} \end{cases}$$

The equivalent representation of this function requires the introduction of two binary variables  $\beta_{11}$  and  $\beta_{12}$ . These binary variables can be defined as follows:

$$\beta_{11} = \begin{cases} 1 & \text{if } 0 < \delta_1^- \leq 50 \\ 0 & \text{Otherwise} \end{cases} \quad \beta_{12} = \begin{cases} 1 & \text{if } 50 \leq \delta_1^- \leq 150 \\ 0 & \text{Otherwise} \end{cases}$$

Thus, the function may take the following equivalent form:

$$\begin{aligned} F_1^-(\delta_1^-) &= \beta_{11}f_1(\delta_1^-) + \beta_{12}f_2(\delta_1^-) \\ &= \beta_{11}(1 - 0,02\delta_1^-) + \beta_{12}(0) = \beta_{11} - 0,02\beta_{11}\delta_1^- \end{aligned}$$

The term  $0,02\beta_{11}\delta_1^-$  is non-linear, so it is possible to obtain a linear formulation by using the linearisation procedure of Oral and Kettani (1992). Then, the linear representation equivalent to this program on the first objective is described as follows:

$$\text{Max} Z = \beta_{11} - \zeta_1$$

Subject to:

$$\begin{aligned} \beta_{12} - \delta_1^- &\leq 0 \\ \delta_1^- - 50\beta_{11} - 150\beta_{12} &\leq 0 \\ 0,02\delta_1^- + 3\beta_{11} - \zeta_1 &\leq 3 \\ \beta_{11} + \beta_{12} &= 1 \\ \beta_{11}, \beta_{12} \in (0,1), \delta_1^- \text{ and } \zeta_1 &\geq 0 \end{aligned}$$

applying the same steps for the three other satisfaction functions.

## Results and discussion

By using LINDO software to optimise the mathematical model (Eq.10), which contains 48 constraints and 30 variables, the results obtained are significant. They show that supplier A dominates all the others, and is considered the best one. Therefore, the demand for 2000 units is shared as follows:

Supplier A:  $x_1 = 850$  units, Supplier B:  $x_2 = 500$  units, Supplier C:  $x_3 = 300$  units, Supplier D:  $x_4 = 350$  units and supplier E:  $x_5 = 0$  units. Note that the total satisfaction level of the DM is about 61%. Based on the output of LINDO, all goals are fully satisfied and the DM preferences are explicitly taken into account. Nevertheless, the results obtained are very sensitive to the threshold values announced by the DM.

## Conclusion

In this paper, the authors put forward a new approach based on FAHP and IGP to help the DM in selecting the best supplier. This approach explicitly takes into account the DM preferences via the satisfaction function concept. To show the effectiveness of the proposed approach, a case study was carried out in a Tunisian company. Based on the results obtained by using LINDO, the proposed approach achieves all objectives with regard to the DM preferences and is very easy to apply. Moreover, it is flexible, which means that it can be adapted to a change in the model's parameters such as specification levels and satisfaction function thresholds and also can be extended to integrate additional objectives. Thus, the authors are convinced that the proposed approach can be considered to be a decision aid. Nevertheless, the number of constraints is significant enough in the mathematical model that the use of metaheuristics or hybrid approaches is highly recommended.

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