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ORIGINAL ARTICLE

Employing fuzzy TOPSIS and SWOT for supplier selection and order allocation problem

S. Mohammad Arabzad · Mazaher Ghorbani · Jafar Razmi · Hadi Shirouyehzad

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Abstract Supplier selection is a multiple criteria decision making (MCDM) problem which is affected by several conflicting factors. In the business market of flaming competition in recent years, more attention has been paid to this problem. In this paper, a model is proposed in two phases. At first, suppliers are evaluated according to both qualitative and quantitative criteria arising from strengths, weaknesses, opportunities, and threats (SWOT) analysis. SWOT, as a useful technique in strategic management, is utilized to determine criteria and deal with suppliers' situation in a competitive market. Moreover, fuzzy set theory is employed to deal with the vagueness of human thought. Then, fuzzy logic is integrated with technique for order preference by similarity to ideal solution (TOPSIS) technique to calculate weights of criteria. In the second phase, results from fuzzy TOPSIS (FTOPSIS) are used as an input for linear programming to allocate orders. Finally, a case study has been used simultaneously to validate the proposed model.

Keywords Supplier selection · Order allocation · Fuzzy TOPSIS · SWOT analysis

S. M. Arabzad
Department of Industrial Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran

M. Ghorbani
Department of Industrial Engineering, Yazd University, Yazd, Iran

J. Razmi (✉)
School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran
e-mail: jrazmi@ut.ac.ir

H. Shirouyehzad
Department of Industrial Engineering, Najafabad Branch, Islamic Azad University, Isfahan, Iran

1 Introduction

It is well known that competition among companies has become fiercer and fiercer and the marginal profit has been becoming thinner and thinner recently. Increasing globalization, diversity of the product range, and increasing customer awareness are making the market(s) highly competitive. Increasing competition has been forcing the manufacturing organization to respond to dynamic demands of the customers [1, 2]. Enterprises today must have better production technology internally and externally, such as supplier capability and customer requirement, for competitive ability. Enterprises must change their attitudes toward the supplier from enemy to partner and consider them as a resource in order to increase the supply chain to rapid response in a dog-eat-dog environment. Private enterprises and listed companies recognized that good supply chain management (SCM) promotes success [3]. Therefore, SCM has generated a substantial amount of interest both among managers and researchers. SCM practices have flourished since the 1990s and now are distinguished as a governing element in strategy and as an effective way of creating value for customers [4]. Managers have traditionally focused on managing internal operations to promote profits, but new concepts that SCM proposed emphasize integrating internal activities and decisions with external enterprise partners to promote competitive capability [3]. Many authors (such as [4–6]) investigated the importance of supplier selection problems and their key roles in achieving SCM goals. Determining suitable suppliers in the supply chain has become a key strategic decision and it has been prominently studied thoroughly in the past four decades [6].

Sonmez [7] defined supplier selection as a "process of finding the suppliers being able to provide the buyer with the right quality products and/or services at the right price, at the right quantities, and at the right time." In the past few decades, there have been major changes in the supplier selection practices. The competition has risen and the market has become globally operating. In such a scenario, it has become highly difficult for industries to produce low-cost and high-quality products successfully without proper suppliers [6]. Reduce purchasing risk, maximize overall value to the purchaser, and build a long-term, reliable relationship between buyers and suppliers are the objectives that supplier selection follows [1, 3, 8]. The number of available alternatives in the current market is on a rise, and hence, it becomes difficult to select a supplier from among a large lot. Also, supplier selection criteria can differ according to the type of the product. In fact, supplier selection is a multiple criteria decision making (MCDM) problem which is affected by several conflicting factors [8–11]. Full literature review in supplier selection scope is available in the literature [4, 5, 12–14].

In the past two decades, an exploding trend in frequency and percentage of outsourcing has occurred in various industrial and construction projects. Particularly, for oil- and gas-related projects, a diverse group of suppliers and consultants are often selected to provide a range of products and services. To now, numerous researches have been done in the context of supplier selection in gas industry. Oliveira and Lourenço [15] discussed the problem of selecting suppliers for the construction of pipeline networks for gas distribution. They developed a multi-source and multi-period model that allocated construction orders to a pool of pre-qualified set of suppliers. Aouam et al. [16] formulated the procurement problem of natural gas as a multi-stage stochastic portfolio model considering as decision variable quantities purchased as spot contracts, future contracts, and call options. Sepehri [17] developed a fundamental framework for supplier portfolio management, including supplier selection and empowerment in gas industry, based on the company's corporate and procurement strategies. Congjun et al. [18] focused on designing a multi-attribute auction mechanism for addressing the decision making problem of multi-attribute and multi-source procurement of a kind of homogeneous continuous divisible goods (such as coal, oil, electricity, and gas).

Researches on the subject of methods that are used in supplier selection problem are abundant. First publications can be traced back to the 1960s. A detailed overview of supplier selection methods till 2013 can be found in the literature [8, 14, 19, 20].

Wang et al. [21] proposed a hierarchical technique for order preference by similarity to ideal solution (TOPSIS) that employs rules based on Euclidean distances for supplier selection. They proposed simplified parameterized metric distance and fuzzy analytical hierarchical process (FAHP) to modify Chen's fuzzy TOPSIS (FTOPSIS) to overcome disadvantages of their model [19]. Önut [22] performed long-term supplier selection using fuzzy analytic network process (FANP) and FTOPSIS in a telecommunications company. Chen et al. [5] utilized strengths, weaknesses, opportunities, and threats (SWOT) to identify an enterprise market strategy based on the competitive strategy. Then, potential suppliers were screened through data envelopment analysis (DEA). Subsequently, TOPSIS technique was adapted to rank potential suppliers. Zeydan et al. [23] considered both qualitative and quantitative variables in evaluating performance for selection of suppliers. Their methodology was realized in two stages. In the first stage, qualitative performance evaluation was performed by using FAHP in finding criteria weights and then FTOPSIS was utilized to transform them into quantitative variable. In the second stage, DEA was performed to rank the suppliers. Lin et al. [24] proposed enterprise resource planning (ERP) to realize the strength and weakness of the purchasing operation. Also, analytic network process (ANP) was used to compute the weight of criteria and sub-criteria. Then, TOPSIS was performed to calculate the final score of each alternative. Amin et al. [25] integrated fuzzy logic with SWOT analysis in the context of supplier selection problem. In their research, weights of internal and external factors were calculated by using linguistic variables. Then, the output of SWOT analysis was applied as an input in the fuzzy linear programming (LP) model.

Considering latest studies in supplier selection problem, lots of various methods of MCDM such as TOPSIS, AHP, and ANP have been used alongside mathematical modeling such as LP and goal programming (GP). It can also be seen that some techniques such as quality function deployment (QFD), SWOT analysis, and Taguchi's loss function [25] have been used less in the literature.

This paper is the expansion of the work of Amin et al. [26]. It should be mentioned that it has some substantial differences as follows. Firstly, in this paper, we consider the importance weight of decision-makers (DMs) which are crucial in real practical cases. Secondly, having used FTOPSIS to determine the importance weight of the criteria and alternatives, the model would be more accurate. MCDM techniques have some advantages in a way that weight of the alternatives can be computed and understood easily. To deal with the practical problems more accurately, this innovation causes better results. Finally, we consider type of the parts for determining weights of internal and external criteria in mathematical modeling.

In this paper, SWOT analysis is used to determine evaluation criteria. Fuzzy logic is integrated with TOPSIS technique to determine weight of criteria and to overcome uncertainty and vagueness of human thought. Moreover, order allocation is conducted with the aid of LP method. It should be mentioned that our model has been designed for solving multi-supplier, multi-criteria, and multi-part problems. Besides, some constraints such as strategic points of view and limited capacity of warehouse are taken into account. Simultaneously, a case study is conducted to show efficiency of the proposed approach.

This paper is organized as follows. Section 2 presents fuzzy logic. Section 3 describes FTOPSIS. In Section 4, a case study is illustrated. Section 5 discusses our proposed model simultaneously with case study. Finally, discussion and conclusions are presented in section 6.

2 Fuzzy logic

Fuzzy sets whose elements have degrees of membership were introduced by Zadeh [27] as an extension of the classical notion of set. Fuzzy sets and fuzzy logic are powerful mathematical tools for modeling uncertain systems in industry. A fuzzy set is also an extension of a crisp set. Crisp sets only allow full membership or non-membership, whereas fuzzy sets allow partial memberships [28].

Among various shapes of fuzzy numbers, we use triangular fuzzy number (TFN), because of its simplicity and popularity. According to Kaufmann and Gupta [29], TFN can be defined as a triplet (a, b, c) where the parameters of a, b, and c, respectively, indicate the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event (as Fig. 1). If we consider two fuzzy numbers, A (a_1, b_1, c_1) and B (a_2, b_2, c_2), important operations used in this study are as below:

$$(a_1,\ b_1,\ c_1) \pm\ (a_2,\ b_2,\ c_2) = (a_1 \pm\ a_2,\ b_1 \pm\ b_2,\ c_1 \pm c_2) \quad (1)$$

$$(a_1,\ b_1,\ c_1) \times\ (a_2,\ b_2,\ c_2) = (a_1 \times\ a_2,\ b_1 \times\ b_2,\ c_1 \times c_2) \quad (2)$$

3 Fuzzy TOPSIS

TOPSIS (technique for order preference by similarity to ideal solution) is proposed by Hwang and Yoon [30]. The basic principle of TOPSIS is that chosen alternatives should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution. According to Shih et al. [31], advantages of TOPSIS are as follows:

- A sound logic that represents the rationale of human choice.
- A scalar value that accounts for both the best and worst alternative, simultaneously.
- A simple computation process that can be easily programmed into a spreadsheet.
- The performance measures of all alternatives on attributes can be visualized on a polyhedron, at least for any two dimensions.

It is often difficult for DMs to assign a precise performance rating to an alternative for the attributes under consideration. The merit of using a fuzzy approach is to assign the relative importance of attributes using fuzzy numbers instead of precise numbers for suiting the real world in fuzzy environment. This section extends TOPSIS to the fuzzy environment [32]. The mathematics concept is borrowed from Buyukozkan et al. [33], Kuo et al. [34], and Wang and Chang [35].

Step 1: Form a committee of DMs and then identify evaluation criteria.

Step 2: Choose appropriate linguistic variables for the importance weights of criteria and linguistic ratings for suppliers.

Step 3: Construct the fuzzy performance/decision matrix and choose the appropriate linguistic variables for the alternatives with respect to criteria

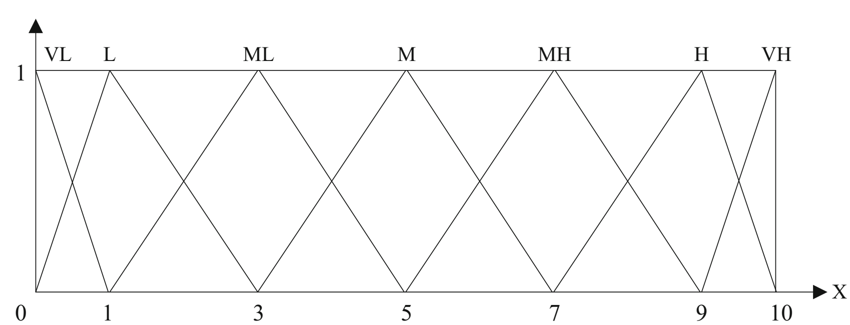
$$\tilde{D} = \begin{matrix} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{matrix} \begin{matrix} C_1 & C_2 & \ldots & C_n \end{matrix} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \ldots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \ldots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \ldots & \tilde{x}_{mn} \end{bmatrix} \end{matrix} \quad (3)$$
$$i = 1, 2 \ldots m;\ j = 1, 2 \ldots n.$$
$$\tilde{x}_{ij} = \frac{1}{k}\left(\tilde{x}_{11} \oplus \ldots \oplus \tilde{x}^k_{ij} \oplus \ldots \oplus \tilde{x}^k_{ij}\right)$$

where $\tilde{x}^k_{ij}$ is the performance rating of alternative A_i with respect to criterion C_j evaluated by the kth expert, and $\tilde{x}^k_{ij} = \left(a^k_{ij}, b^k_{ij}, c^k_{ij}\right)$.

Step 4: Normalize the fuzzy decision matrix.

The normalized fuzzy decision matrix denoted by

Fig. 1 A linguistic scale [4]



* VL (Very Low), L (Low), ML (Medium Low), M (Medium), MH (Medium High), H (High), VH (Very High)

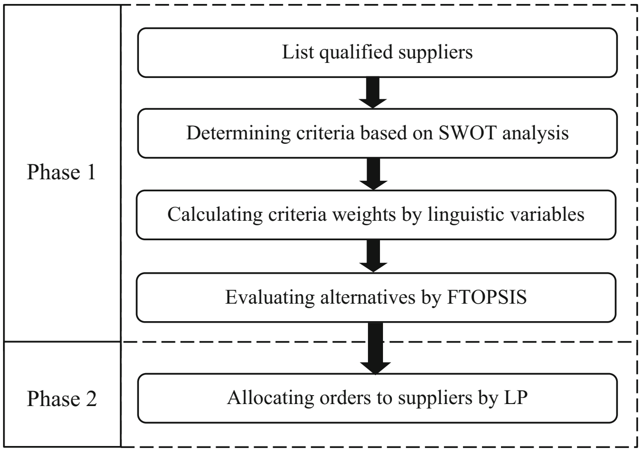


Fig. 2 The proposed model for supplier selection

$\widetilde{R}$ is shown as the following formula:

$$\widetilde{\boldsymbol{R}} = \left[\widetilde{r}_{ij}\right]_{m\times n}, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n. \quad (4)$$

Then, the normalization process can be performed by the following formula: $\widetilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+}\right)$, $c_j^+ = \max\{c_{ij} | i = 1, 2, \ldots, n\}$ or we can set the best aspired level c_j^+ and j=1,2,…,n is equal to one; otherwise, the worst is zero.

The normalized $\widetilde{r}_{ij}$ is still triangular fuzzy numbers. For trapezoidal fuzzy numbers, the normalization process can be conducted in the same way. The weighted fuzzy normalized decision matrix is shown as the following matrix $\widetilde{V}$:

$$\widetilde{\boldsymbol{V}} = \left[\widetilde{v}_{ij}\right]_{m\times n}, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n. \quad (5)$$

where $\widetilde{v}_{ij} = \widetilde{r}_{ij} \otimes \widetilde{w}_j$. Also, where $\widetilde{w}_j$ represents the importance weight of criterion C_j.

Step 5: Determine the fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS).

According to the weighted normalized fuzzy decision matrix, we know that the elements $\widetilde{v}_{ij}$ are normalized positive TFN and their ranges belong to the closed interval [0, 1]. Then, we can define the FPIS A^+ (aspiration levels) and FNIS A^- (the worst levels) as the following formula:

$$A^+ = \left\{\widetilde{v}_1^*, \ldots, \widetilde{v}_j^*, \ldots, \widetilde{v}_n^*\right\} \quad (6)$$

$$A^- = \left\{\widetilde{v}_1^-, \ldots, \widetilde{v}_j^-, \ldots, \widetilde{v}_1^-\right\} \quad (7)$$

where

$$\widetilde{v}_j^* = (1, 1, 1) \otimes \widetilde{w}_j = \left(aw_j, bw_j, cw_j\right) \text{ and } \widetilde{v}_j^- = (0, 0, 0), j = 1, 2, \ldots n.$$

Table 1 Importance weights of decision-makers

Decision-makers	Importance weights
DM_1	VH
DM_2	VH
DM_3	M
DM_4	MH

Table 2 Importance weight of criteria from four decision-makers

Criteria	Decision-makers			
	DM_1	DM_2	DM_3	DM_4
C_1	H	H	MH	MH
C_2	MH	VH	VH	VH
C_3	H	MH	M	M
C_4	M	M	H	H
C_5	M	MH	MH	M
C_6	M	ML	M	VL
C_7	M	M	L	MH
C_8	M	MH	M	VL
C_9	H	M	H	MH

Step 6: Calculate the distance of each alternative from FPIS and FNIS.

The distances $\left(\widetilde{D}_i^+ \ and \ \widetilde{D}_i^-\right)$ of each alternative from A^+ to A^- can be currently calculated by the area compensation method.

$$\widetilde{D}_i^+ = \sum_{j=1}^{n} d\left(\widetilde{v}_{ij}, \widetilde{v}_j^*\right), i = 1, 2, \ldots, m; j = 1, 2, \ldots, n. \quad (8)$$

$$\widetilde{D}_i^- = \sum_{j=1}^{n} d\left(\widetilde{v}_{ij}, \widetilde{v}_j^-\right), i = 1, 2, \ldots, m; j = 1, 2, \ldots, n. \quad (9)$$

Step 7: Obtain the closeness coefficients (relative gaps-degree) and improve alternatives for achieving aspiration levels in each criterion.

$\widetilde{CC_i}$ is defined to determine the fuzzy gaps-degree based on fuzzy closeness coefficients for improving alternatives; once the $\widetilde{D}_i^+$ and $\widetilde{D}_i^-$ of each alternative have been calculated. Calculate similarities to ideal solution. This step solves the

Table 3 Performance ratings of five suppliers by decision-makers under various criteria

Criteria	Suppliers	P_1				P_2			
		DM_1	DM_2	DM_3	DM_4	DM_1	DM_2	DM_3	DM_4
C_1	A_1	ML	MH	M	ML	ML	L	ML	M
	A_2	M	L	H	H	ML	ML	M	M
	A_3	M	M	MH	M	ML	MH	H	MH
	A_4	ML	MH	H	H	M	VH	ML	MH
	A_5	H	H	H	VH	M	MH	ML	H
C_2	A_1	ML	H	M	M	M	MH	ML	ML
	A_2	ML	M	MH	MH	M	H	MH	ML
	A_3	ML	ML	MH	MH	M	ML	MH	M
	A_4	VH	MH	ML	M	ML	MH	ML	M
	A_5	MH	MH	M	H	VH	MH	H	VH
C_3	A_1	VH	VH	MH	M	M	L	L	L
	A_2	MH	M	L	VH	ML	MH	M	VH
	A_3	M	VH	M	VH	H	VH	VH	H
	A_4	M	M	H	ML	VH	H	L	L
	A_5	M	L	ML	VH	VH	MH	H	VH
C_4	A_1	H	H	ML	H	M	H	ML	ML
	A_2	MH	M	H	VH	MH	ML	MH	ML
	A_3	H	M	MH	H	MH	ML	H	M
	A_4	MH	ML	ML	ML	MH	ML	ML	H
	A_5	M	MH	M	L	VH	VH	M	MH
C_5	A_1	ML	H	M	MH	MH	VL	ML	ML
	A_2	ML	H	H	ML	H	H	MH	ML
	A_3	MH	ML	H	VH	M	VH	MH	MH
	A_4	ML	L	VH	MH	ML	H	MH	M
	A_5	VH	M	H	H	M	MH	ML	VH
C_6	A_1	M	ML	L	H	M	ML	ML	ML
	A_2	H	MH	H	VH	ML	ML	H	MH
	A_3	L	VH	VH	VH	H	ML	H	M
	A_4	ML	MH	ML	ML	ML	ML	VH	MH
	A_5	MH	H	H	VH	VH	MH	M	MH
C_7	A_1	VH	ML	M	H	MH	M	MH	MH
	A_2	MH	MH	H	ML	H	H	H	H
	A_3	MH	L	H	VH	M	VH	VL	ML
	A_4	MH	H	VH	MH	ML	MH	H	H
	A_5	M	M	H	H	M	ML	M	ML
C_8	A_1	VH	MH	M	VH	ML	M	ML	MH
	A_2	MH	L	H	H	MH	H	M	H
	A_3	MH	M	H	M	ML	VH	H	ML
	A_4	MH	MH	VH	H	M	MH	ML	H
	A_5	VL	H	H	VH	M	ML	ML	ML
C_9	A_1	H	ML	MH	H	M	L	ML	M
	A_2	ML	MH	L	VH	ML	MH	H	M
	A_3	MH	VH	M	VH	H	M	H	ML
	A_4	MH	MH	H	ML	ML	H	VH	H
	A_5	MH	H	ML	VH	VH	ML	M	M

Table 4 Normalized fuzzy decision matrix (internal criteria, part 1)

Suppliers	Internal criteria			
	C_1	C_2	C_3	C_4
A_1	(0.25 0.45 0.85)	(0.35 0.55 0.73)	(0.65 0.80 0.90)	(0.55 0.75 0.87)
A_2	(0.43 0.60 0.75)	(0.35 0.55 0.75)	(0.43 0.57 0.73)	(0.60 0.77 0.90)
A_3	(0.35 0.55 0.75)	(0.30 0.50 0.70)	(0.60 0.75 0.85)	(0.55 0.75 0.90)
A_4	(0.50 0.70 0.85)	(0.45 0.63 0.77)	(0.35 0.55 0.73)	(0.20 0.40 0.60)
A_5	(0.75 0.93 1.00)	(0.50 0.70 0.87)	(0.33 0.47 0.63)	(0.27 0.45 0.65)

Table 5 Normalized fuzzy decision matrix (external criteria, part 1)

Suppliers	External criteria				
	C_5	C_6	C_7	C_8	C_9
A_1	(0.40 0.60 0.77)	(0.27 0.45 0.63)	(0.50 0.67 0.80)	(0.65 0.80 0.90)	(0.50 0.70 0.85)
A_2	(0.40 0.60 0.75)	(0.70 0.87 0.97)	(0.45 0.65 0.83)	(0.47 0.65 0.80)	(0.37 0.53 0.67)
A_3	(0.55 0.73 0.85)	(0.67 0.77 0.83)	(0.53 0.67 0.80)	(0.45 0.65 0.83)	(0.65 0.80 0.90)
A_4	(0.37 0.53 0.67)	(0.20 0.40 0.60)	(0.65 0.83 0.95)	(0.65 0.83 0.95)	(0.45 0.65 0.83)
A_5	(0.65 0.83 0.93)	(0.70 0.87 0.97)	(0.50 0.70 0.85)	(0.57 0.70 0.77)	(0.55 0.73 0.85)

similarities to an ideal solution by formula

$$\widetilde{CC}_i^* = \frac{\tilde{d}_i^-}{\tilde{d}_i^* + \tilde{d}_i^-}, \quad i = 1, 2 \ldots m. \quad (10)$$

Step 8: Rank the preference order. The $\widetilde{CC}_i^*$ is between 0 and 1. The larger CC_i^* is, the better alternative A_i is.

4 Case study

The evolution of gas industry and its importance started from the last century and Iran, as the second largest owner of the natural gas resources in the world, has been motivated to produce devices and equipment for gas industry. Gassouzan Company was the first industrial company in Iran to produce gas pressure regulator in accordance with the National Iranian Gas Company (NIGC) standards in 1981 based on knowledge and technology. Now, in its 32nd year of effort, Gassouzan Company enjoys an important and key position in the production and supply chain of natural gas for metering and regulating equipment in Iran and now is a pioneer in gas industry. Gassouzan Company increased its activities for both national and international markets. Recently, the company started to produce reducing and metering gas stations.

Gas industry needs facilities with the highest quality to be as efficient as possible. On the other hand, in order to be responsive, it is necessary that suppliers support gas companies with minimum delay. Therefore, it is crucial to select reliable suppliers which guarantee the whole supply chain.

Safety shut off valve (SSV) and safety relief valve (SRV) are two main parts that are used in assembling gas stations. These parts should be bought due to economic considerations and lack of construction technology. France, Germany, and Italy are the most well-known manufacturers of these parts in the international market. Almost all the potential suppliers are capable of providing both parts. There are two parts that should be bought in this case study. These parts are regarded

Table 6 Normalized fuzzy decision matrix (internal criteria, part 2)

Suppliers	Internal criteria			
	C_1	C_2	C_3	C_4
A_1	(0.13 0.30 0.50)	(0.25 0.45 0.65)	(0.07 0.20 0.40)	(0.30 0.50 0.67)
A_2	(0.20 0.40 0.60)	(0.40 0.60 0.77)	(0.45 0.63 0.77)	(0.30 0.50 0.70)
A_3	(0.45 0.65 0.83)	(0.30 0.50 0.70)	(0.80 0.95 1.00)	(0.40 0.60 0.77)
A_4	(0.45 0.63 0.77)	(0.25 0.45 0.65)	(0.40 0.53 0.65)	(0.35 0.55 0.73)
A_5	(0.40 0.60 0.77)	(0.75 0.90 0.97)	(0.75 0.90 0.97)	(0.65 0.80 0.90)

Table 7 Normalized fuzzy decision matrix (external criteria, part 2)

Suppliers	External criteria				
	C_5	C_6	C_7	C_8	C_9
A_1	(0.17 0.33 0.50)	(0.15 0.35 0.55)	(0.45 0.65 0.85)	(0.25 0.45 0.65)	(0.17 0.35 0.55)
A_2	(0.50 0.70 0.85)	(0.35 0.55 0.73)	(0.70 0.90 1.00)	(0.55 0.75 0.90)	(0.40 0.60 0.77)
A_3	(0.55 0.73 0.87)	(0.45 0.65 0.80)	(0.33 0.45 0.57)	(0.45 0.63 0.75)	(0.45 0.65 0.80)
A_4	(0.40 0.60 0.77)	(0.40 0.57 0.73)	(0.50 0.70 0.85)	(0.40 0.60 0.77)	(0.60 0.77 0.87)
A_5	(0.45 0.63 0.77)	(0.55 0.73 0.87)	(0.20 0.40 0.60)	(0.15 0.35 0.55)	(0.40 0.57 0.73)

as basic components in reducing and metering gas stations. Purchasing is an important activity that affects directly the competitiveness of a company. Top management decided to constitute a committee to evaluate and select suppliers and ultimately allocate orders to selected suppliers. Therefore, the committee was obligated to select suppliers based on managers' strategic viewpoint and determine allocated order for them. The two-phase model is utilized to tackle this problem. In the first phase, suppliers are evaluated based on SWOT analysis, and in the second phase, allocated order is determined.

Table 8 Weighted normalized fuzzy decision matrix (internal criteria, part 1)

Suppliers	Internal criteria			
	C_1	C_2	C_3	C_4
A_1	(0.107 0.308 0.570)	(0.173 0.399 0.634)	(0.224 0.460 0.711)	(0.151 0.390 0.656)
A_2	(0.183 0.411 0.658)	(0.173 0.399 0.656)	(0.147 0.331 0.573)	(0.165 0.403 0.675)
A_3	(0.151 0.377 0.658)	(0.149 0.363 0.613)	(0.207 0.431 0.671)	(0.151 0.390 0.675)
A_4	(0.215 0.479 0.746)	(0.223 0.453 0.678)	(0.121 0.316 0.573)	(0.055 0.208 0.450)
A_5	(0.323 0.634 0.877)	(0.247 0.507 0.766)	(0.112 0.273 0.494)	(0.076 0.234 0.487)

Table 9 Weighted normalized fuzzy decision matrix (external criteria, part 1)

Suppliers	External criteria				
	C_5	C_6	C_7	C_8	C_9
A_1	(0.102 0.267 0.554)	(0.031 0.109 0.278)	(0.099 0.243 0.484)	(0.132 0.266 0.491)	(0.170 0.385 0.682)
A_2	(0.102 0.267 0.536)	(0.079 0.212 0.434)	(0.089 0.234 0.499)	(0.096 0.216 0.436)	(0.127 0.289 0.542)
A_3	(0.140 0.323 0.608)	(0.076 0.188 0.367)	(0.104 0.243 0.484)	(0.091 0.216 0.450)	(0.221 0.440 0.722)
A_4	(0.096 0.234 0.483)	(0.023 0.097 0.267)	(0.128 0.297 0.575)	(0.132 0.274 0.518)	(0.153 0.357 0.662)
A_5	(0.166 0.367 0.661)	(0.079 0.212 0.434)	(0.099 0.252 0.514)	(0.116 0.233 0.522)	(0.187 0.399 0.682)

Table 10 Weighted normalized fuzzy decision matrix (internal criteria, part 2)

Suppliers	Internal criteria			
	C_1	C_2	C_3	C_4
A_1	(0.054 0.205 0.439)	(0.124 0.326 0.569)	(0.026 0.115 0.316)	(0.083 0.260 0.506)
A_2	(0.086 0.274 0.527)	(0.198 0.435 0.678)	(0.155 0.359 0.612)	(0.083 0.260 0.515)
A_3	(0.193 0.445 0.724)	(0.149 0.363 0.613)	(0.276 0.546 0.790)	(0.110 0.312 0.581)
A_4	(0.193 0.428 0.680)	(0.124 0.326 0.569)	(0.138 0.302 0.513)	(0.096 0.286 0.544)
A_5	(0.172 0.411 0.680)	(0.371 0.653 0.853)	(0.259 0.517 0.770)	(0.179 0.416 0.675)

Table 11 Weighted normalized fuzzy decision matrix (external criteria, part 2)

Suppliers	External criteria				
	C_5	C_6	C_7	C_8	C_9
A_1	(0.045 0.145 0.358)	(0.017 0.085 0.245)	(0.089 0.234 0.514)	(0.506 0.150 0.354)	(0.059 0.193 0.441)
A_2	(0.127 0.311 0.608)	(0.039 0.133 0.323)	(0.138 0.324 0.605)	(0.111 0.249 0.491)	(0.136 0.330 0.622)
A_3	(0.140 0.323 0.626)	(0.051 0.158 0.356)	(0.064 0.162 0.348)	(0.091 0.208 0.409)	(0.153 0.357 0.642)
A_4	(0.102 0.267 0.554)	(0.045 0.139 0.323)	(0.099 0.252 0.514)	(0.081 0.199 0.422)	(0.204 0.426 0.702)
A_5	(0.115 0.278 0.554)	(0.062 0.176 0.389)	(0.039 0.144 0.353)	(0.030 0.116 0.300)	(0.136 0.316 0.582)

Table 12 FPIS and FNIS (internal criteria, part 1)

	Internal criteria			
	C_1	C_2	C_3	C_4
A^+	(0.877 0.877 0.877)	(0.766 0.766 0.766)	(0.711 0.711 0.711)	(0.675 0.675 0.675)
A^-	(0.107 0.107 0.107)	(0.149 0.149 0.149)	(0.112 0.112 0.112)	(0.055 0.055 0.055)

Table 13 FPIS and FNIS (external criteria, part 1)

	External criteria				
	C_5	C_6	C_7	C_8	C_9
A^+	(0.661 0.661 0.661)	(0.434 0.434 0.434)	(0.575 0.575 0.575)	(0.518 0.518 0.518)	(0.722 0.722 0.722)
A^-	(0.096 0.096 0.096)	(0.023 0.023 0.023)	(0.889 0.889 0.889)	(0.091 0.091 0.091)	(0.127 0.127 0.127)

5 The proposed model

Considering strategic viewpoint of the organization, criteria are classified into internal and external based on the strengths, weaknesses, opportunities, and threats of the SWOT analysis. Then, FTOPSIS technique is utilized to evaluate suppliers based on the internal and external criteria. FTOPSIS approach helps to convert DMs' preference and experience to meaningful results by applying linguistic values to assess each criterion and alternative suppliers. In order to consider this in calculations, it is necessary to integrate fuzzy logic to the proposed model. Managers and DMs in the company considered strategic viewpoint in the supplier selection problem. This long-term viewpoint causes vagueness in estimating cost parameters. Therefore, to deal with ambiguity and vagueness in human mind, fuzzy set theory was used for cost parameter estimation. FTOPSIS is one of the most popular techniques in selection problem [28, 32, 36]. The proposed model for supplier selection contains two following phases (Fig. 2). This model has been applied in Gassouzan Company, where five suppliers were candidates for supplying company needs for the mentioned two parts needed in construction of a new product. As said before, for economic consideration and lack of production technology, the committee decided to buy these parts. Hence, the proposed model was considered to deal with this problem. Therefore, a committee including four DMs

Table 14 FPIS and FNIS (internal criteria, part 2)

	Internal criteria			
	C_1	C_2	C_3	C_4
A^+	(0.724 0.724 0.724)	(0.853 0.853 0.853)	(0.790 0.790 0.790)	(0.675 0.675 0.675)
A^-	(0.537 0.537 0.537)	(0.124 0.124 0.124)	(0.026 0.026 0.026)	(0.055 0.055 0.055)

Table 15 FPIS and FNIS (external criteria, part 2)

	External criteria				
	C_5	C_6	C_7	C_8	C_9
A^+	(0.626 0.626 0.626)	(0.389 0.389 0.389)	(0.605 0.605 0.605)	(0.491 0.491 0.491)	(0.702 0.702 0.702)
A^-	(0.045 0.045 0.045)	(0.017 0.017 0.017)	(0.039 0.039 0.039)	(0.030 0.030 0.030)	(0.059 0.059 0.059)

such as production manager, warehouse manager, business manager, and technical manager are chosen.

5.1 Phase 1: supplier evaluation

In this section, the proposed model is described in 11 steps simultaneously with the case study.

Step 1: First, it is necessary to list a set of suppliers and evaluation criteria. Therefore, members of the committee select five suppliers from the set of potential suppliers for the two parts (P_1 and P_2). These suppliers are selected after pre-assessment phase defined by maximum financial ability. The comprehensive list of criteria proposed by Dickson [37] was represented to DMs to select the most suitable ones to the case study. Among them, SWOT analysis was used to categorize the criteria into two groups of external and internal to make it possible to evaluate suppliers from two different aspects. Finally, DMs determined the appropriate criteria by brain storming. In the previous methods, external criteria were ignored, but SWOT enables us to take into account opportunities and threats. An important point considering two different aspects, i.e., internal and external criteria, is that failure in one of these aspects is not compensated by success in another aspect. For this purpose, committee defines criteria as below:

Price (C_1), quality (C_2), delivery (C_3), and after sales services (C_4) are considered as internal criteria, while reputation and position in industry (C_5), design capability (C_6), financial stability and credit strength (C_7), equipment and capacity (C_8), and geographical location (C_9) are considered as external criteria. On the other hand, price (C_1) and delivery (C_3) are negative criteria that mean less is better and the others are positive meaning more is better.

Step 2: Next, DMs use linguistic weighting variables as shown in Fig. 1 to assess the importance of criteria. It should be mentioned that the importance of each DM and their input into the decision are addressed in Table 1. It is worth to note that the importance weight of each DM is determined according to the hierarchy of the organization.

Members of committee believed that the importance weights of criteria are independent from type of parts. It means that each part is explored separately by SWOT and importance weight of internal and external criteria are determined independently. Results are shown in Table 2.

Step 3: In this step, DMs use linguistic rating variables shown in Fig. 1 to evaluate the ratings of candidate suppliers with respect to each criterion. The performance ratings of five suppliers by DMs under various criteria are shown in Table 3.

Step 4: Using Eqs. 3 and 4, the linguistic evaluations shown in Tables 1 and 2 are converted into TFN to construct the fuzzy decision matrix and determine the fuzzy weight of each criterion, as in Table 3 (see Tables 23, 24, 25, and 26 in Appendix 1).

Step 5: Using Eq. 4, the normalized fuzzy decision matrix is constructed (Tables 4, 5, 6, and 7).

Step 6: Weighted normalized fuzzy decision matrix is constructed using Eq. 5 (Tables 8, 9, 10, and 11).

Step 7: Determine FPIS and FNIS by Eqs. 6 and 7 (Tables 12, 13, 14, and 15).

Table 16 Computations of d^+, d^-, and CC_i^* (internal criteria, part 1)

P_1	Supplier	d^+	d^-	d^++d^-	CC_i^*
Internal criteria	A_1	1.6506	1.4135	3.0641	0.4613
	A_2	1.6414	1.4031	3.0445	0.4609
	A_3	1.6377	1.4362	3.0499	0.4672
	A_4	1.7020	1.3219	3.0239	0.4371
	A_5	1.5736	1.4783	3.0519	0.4844

Table 17 Computations of d^+, d^-, and CC_i^* (external criteria, part 1)

P_1	Supplier	d^+	d^-	d^++d^-	CC_i^*
External criteria	A_1	1.6920	1.2902	2.9822	0.4326
	A_2	1.7293	1.2562	2.9855	0.4208
	A_3	1.5869	1.4031	2.9900	0.4693
	A_4	1.7030	1.2962	2.9992	0.4322
	A_5	1.5596	1.4578	3.0174	0.4831

Table 18 Computations of d^+, d^-, and CC_i^* (internal criteria, part 2)

P$_2$	Supplier	d^+	d^-	d^++d^-	CC_i^*
Internal criteria	A$_1$	2.1390	0.9617	3.1007	0.3102
	A$_2$	1.8060	1.3431	3.1491	0.4265
	A$_3$	1.5807	1.6400	3.2207	0.5092
	A$_4$	1.8026	1.3323	3.1349	0.4250
	A$_5$	1.3366	1.8900	3.2266	0.5857

Step 8: After that, calculate the distance of each supplier from FPIS and FNIS regarding each criterion, respectively (Tables 27, 28, 29, and 30, see Appendix 2). The distance between them can be calculated by using the vertex method as [35]:

$$d_v\left(\widetilde{m},\widetilde{n}\right) = \sqrt{\frac{1}{3}\left[(m_1-n_1)^2+(m_2-n_2)^2+(m_3-n_3)^2\right]} \quad (11)$$

Step 9: Calculate d^+ and d^- of five candidate suppliers and closeness coefficients by using Eqs. 8, 9, and 10 (Tables 16, 17, 18, and 19).

Step 10: Finally, determine the benchmarking value for the overall external and internal criteria by inserting each CC_i^* in Table 20. Benchmarking value is defined as the average of total weighted values. By calculating the coordinated values for each supplier with Eqs. 12 and 13 and comparing the results, these values can be demonstrated on four-quadrant coordinate. Benchmarking value is subtracted from total weighted scores. The final value will be the coordinated value of the compared supplier in the SWOT matrix. Coordinated value will be within −1 and +1. The supplier possesses strengths and opportunities when the coordinated value is larger than the benchmarking value. On the other hand, the supplier is comparatively weak and faces threats when the coordinated value is smaller than the benchmarking value.

Table 19 Computations of d^+, d^-, and CC_i^* (external criteria, part 2)

P$_2$	Supplier	d^+	d^-	d^++d^-	CC_i^*
External criteria	A$_1$	1.9507	1.0576	3.0083	0.3516
	A$_2$	1.5613	1.5831	3.1444	0.5035
	A$_3$	1.6605	1.4063	3.0668	0.4586
	A$_4$	1.5991	1.4993	3.0984	0.4839
	A$_5$	1.7900	1.2598	3.0498	0.4131

$$\mathrm{IC}_{ij} = I_{ij}-\mathrm{IB}_i, \quad i=1,2,\ldots,n, \quad j=1,2,\ldots,m \quad (12)$$

$$\mathrm{EC}_{ij} = E_{ij}-\mathrm{EB}_i, \quad i=1,2,\ldots,n, \quad j=1,2,\ldots,m \quad (13)$$

where IC_{ij} is the internal coordinated value of the jth supplier for part i, I_{ij} is the internal total weighted value of the jth supplier for part i, IB_i is the benchmarking value of the internal assessment for part i, EC_{ij} is the external coordinated value of the jth supplier for part i, E_{ij} is the external total weighted value of the jth supplier for part i, and EB_i is the benchmarking value of the external assessment for part i.

Two groups of data can be obtained from the above calculations as shown in Table 20. One is the coordinated value used to compare internal assessment of the suppliers and the other belongs to external assessment. Thus, the position of each supplier can be easily depicted. Comparative analysis now can be conducted based on SWOT matrix. It is obvious that the position in the quarter of strengths and opportunities is the most suitable position. Figure 3a and b can help DMs see the position of suppliers based on type of the products.

Step 11: Determine the relative importance weights of internal and external criteria for each part. In this research, multiple products are considered. To this end, based on the calculated CC_i^* (Tables 16, 17, 18, and 19), the relative importance weights are determined using Eqs. 14 and 15.

$$\alpha_{\mathrm{int},i} = \frac{\sum \mathrm{CC}^*_{\mathrm{int}\,,\,i}}{\sum \mathrm{CC}^*_{\mathrm{int}\,,\,i}+\sum \mathrm{CC}^*_{\mathrm{ext}\,,\,i}}, \quad i=1,\ldots,n \quad (14)$$

$$\alpha_{ext,i} = \frac{\sum CC^*_{ext,i}}{\sum CC^*_{int,i}+\sum CC^*_{ext,i}}, \quad i=1,\ldots,n \quad (15)$$

The calculated importance weights of internal and external criteria (Table 21) are used in order allocation phase.

5.2 Phase 2: order allocation

In this phase, a mixed integer linear programming (MILP) is proposed to determine the order quantity for each supplier. This model is based on multiple parts along with internal and external criteria. In this case, each supplier can produce multiple parts with limited and constant capacity.

5.2.1 Notations

Decision variables

X_{ij} the amount of parts i (i=1, 2,…, n), purchased from supplier j (j=1, 2,…, n).

Parameters

$\alpha_{\text{int},i}$ Weight of part i according to internal criteria
$\alpha_{\text{ext},i}$ Weight of part i according to external criteria
I_{ij} Internal total weighted value for part i and supplier j from SWOT analysis
E_{ij} External total weighted value for part i and supplier j from SWOT analysis
v_{ij} Capacity of supplier j for part i
t_{ij} Minimum purchase quantity of part i from supplier j
$D_{i\ \max}$ Maximum demand for part i
$D_{i\ \min}$ Minimum demand for part i
g_i Unit volume of part i
h Total capacity of warehouse

5.2.2 The mathematical model

The objective function and set of constraints involved are set out in Eqs. 16, 17, 18, 19, and 20:

$$\text{Max} \sum_{i=1}^{n} \sum_{j=1}^{m} \left(\alpha_{\text{int},i} I_{ij} + \alpha_{\text{ext},i} E_{ij}\right) X_{ij} \quad (16)$$

$$\text{s.t.} \quad D_{i\ \min} \le \sum_{j=1}^{m} X_{ij} \le D_{i\ \max} \quad \forall \quad i \quad (17)$$

$$X_{ij} \le v_{ij} \quad \forall i, j \quad (18)$$

$$t_{ij} \le X_{ij} \quad \forall i, j \quad (19)$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} g_i X_{ij} \le h \; X_{ij} \ge 0, \text{integer} \; i = 1, 2, \ldots, n, \quad j = 1, 2, \ldots, m \quad (20)$$

- Equation (16) is the objective function of the model. It refers to the value of cooperation between supplier and customer. Equations (17, 18, 19, 20, and 21) describe the list of constraints introduced into the model,
- Equation (17) determines the maximum demand for the parts,
- Equation (18) describes the maximum capacity of ith supplier,
- Equation (19) defines the minimum level of purchasing part from each supplier based on minimum of 70 % of demand for each part. This criterion was explained by Razmi et al. [37]. They have applied four attributes composed of lead time, on-time delivery, quality, and shipment cost in order to present the long-term relationship. In this research, this strategic decision is determined by top management and hence is considered in the model as a constraint.
- Equation (20) describes the inventory capacity limitation according to the capacity of a warehouse.

5.2.3 The mathematical programming assumptions

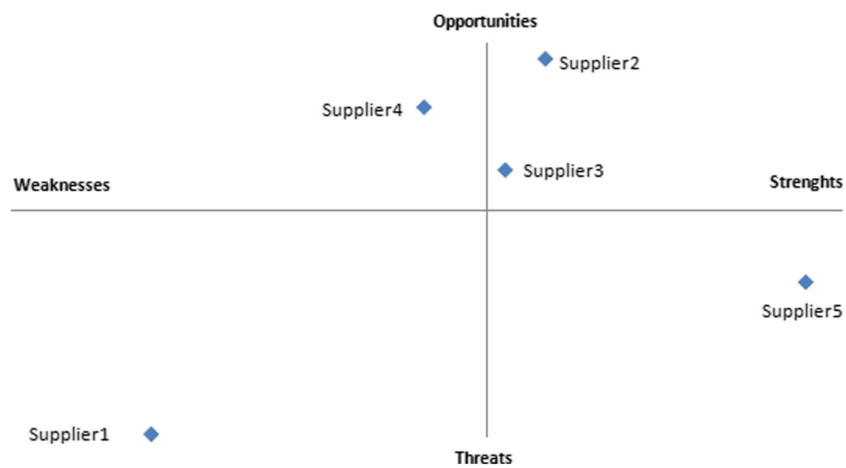
There are some assumptions considered in the proposed allocation programming such as the following:

- Although only one objective function has been noted, this objective includes all the nine pointed criteria considering the obtained importance weight factors. In fact, instead of considering some individual objective functions and doing trade-off, the authors integrate these allocating objectives in one special objective using the concept of SWOT analysis and employing FTOPSIS.

Table 20 Coordinated values under the SWOT analysis

	A_1	A_2	A_3	A_4	A_5	Benchmarking value
Internal total weighted value for part 1	0.4613	0.4609	0.4672	0.4371	0.4844	0.4622
Internal total weighted value for part 2	0.3102	0.4265	0.5092	0.4250	0.5857	0.4513
Internal coordinated value for part 1 (x-axis)	−0.0009	−0.0013	0.0050	−0.0250	0.0222	
Internal coordinated value for part 2 (x-axis)	−0.1412	0.0248	0.0079	−0.0263	0.1344	
External total weighted value for part 1	0.4326	0.4208	0.4693	0.4322	0.4831	0.4476
External total weighted value for part 2	0.3516	0.5035	0.4586	0.4839	0.4131	0.4421
External coordinated value for part 1 (y-axis)	−0.0150	−0.0268	0.0217	−0.0154	0.0355	
External coordinated value for part 2 (y-axis)	−0.0906	0.0614	0.0164	0.0418	−0.0290	

(a) Part 1



(b) Part 2

Fig. 3 Position of suppliers for supplying part 1 (**a**) and part 2 (**b**) in SWOT matrix

- Suppliers are evaluated through the cost criterion qualitatively considering fuzzy concept. In fact, some cost parameters such as ordering and shipment cost have included the suppliers' price criterion (C_1) implicitly.
- The model has been made for one period and the demands for each product have been considered deterministic. In this situation, the holding cost and shortage cost parameter are meaningless. Therefore, this parameter has not been considered in the model.
- The lead-time criterion and some relevant risks and its consequences are also considered as delivery criterion (C_3). Due to this viewpoint, some potential supply risks related to supply raw material from each supplier are considered qualitatively while suppliers' evaluation by DMs.

5.2.4 Solving the mathematical programming

Data of Table 21 are used as inputs for mathematical modeling as follows:

Table 21 Input data for the mathematical model

	$\alpha_{\text{int},i}$	$\alpha_{\text{ext},i}$	$D_{i\ \max}$	g_i	h
P_1	0.5080	0.4920	150	0.4	168
P_2	0.5052	0.4948	380	0.3	

Table 22 Results of the mathematical programming model

	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
Part 1	0	0	45	0	90
Part 2	0	0	180	0	200

$$\begin{array}{lll}
\text{Max} & (0.5080) \times [0.4613\,X_{11} + 0.4609\,X_{12} + 0.4672\,X_{13} + 0.4371\,X_{14} + 0.4844\,X_{15}] & + \\
& (0.4920) \times [0.4326\,X_{11} + 0.4208\,X_{12} + 0.4693\,X_{13} + 0.4322\,X_{14} + 0.4831\,X_{15}] & + \\
& (0.5052) \times [0.3102\,X_{21} + 0.4265\,X_{22} + 0.5092\,X_{23} + 0.4250\,X_{24} + 0.5857\,X_{25}] & + \\
& (0.4948) \times [0.3516\,X_{21} + 0.5035\,X_{22} + 0.4586\,X_{23} + 0.4839\,X_{24} + 0.4131\,X_{25}] & \\
\text{s.t.} & X_{11} + X_{12} + X_{13} + X_{14} + X_{15} \le 150 & \\
& X_{21} + X_{22} + X_{23} + X_{24} + X_{25} \le 380 & \\
& X_{11} \le 70,\ X_{12} \le 85,\ X_{13} \le 70,\ X_{14} \le 100,\ X_{15} \le 90 & \\
& X_{21} \le 150,\ X_{22} \le 200,\ X_{23} \le 250,\ X_{24} \le 200,\ X_{25} \le 200 & \\
& X_{13} + X_{15} \ge 105 & \\
& X_{22} + X_{23} \ge 266 & \\
& 0.4\ (X_{11} + X_{12} + X_{13} + X_{14} + X_{15}) + 0.3\ (X_{21} + X_{22} + X_{23} + X_{24} + X_{25}) \le 168 & \\
& X_{ij} \ge 0, \text{int} \quad i = 1, 2, \quad j = 1, 2, 3, 4, 5 & (21)
\end{array}$$

This MILP optimization problem with maximization objective is solved by LINGO 9 software. Output of the model is the allocated order to each supplier. Results of the proposed model are illustrated in Table 22. So, it can be concluded that the company purchases the needed parts from suppliers 3 and 5. According to management policies, to have long-term relations with suppliers, it should be noted that minimum level of purchasing is also considered as a constraint in our model.

6 Discussion and conclusions

In this paper, candidate suppliers were identified and then evaluation criteria were defined by considering strategic viewpoint. Then, SWOT analysis categorized criteria into two groups of external and internal. The results of evaluation from FTOPSIS and determined constraints were considered as inputs for MILP and the output was the allocated quantity to each supplier.

In business competition, each company has its own strategy. Therefore, the proposed model must be adjusted according to the company's strategy. One of these strategies is having a long-term relationship with desired suppliers to follow the market and work with them as a supply chain efficiently. To this end, a constraint was defined for purchasing at least 70 % of demand from the qualified suppliers for each part.

To perform SWOT analysis, a matrix was defined to identify the position of suppliers. Considering strengths, weaknesses, opportunities, and threats, four regions were made. Certainly, suppliers that are in opportunities-strengths region are the best, and those that are in the threats-weaknesses region are the worst. According to Fig. 2, the best suppliers for providing part 1 are suppliers 3 and 5, while supplier 3 is the best for supplying part 2. Results from Table 22 also show that there is no allocated order for suppliers 1, 2, and 4.

In Gassouzan Company, suppliers were selected according to the price and there was no systematic approach to select suppliers. Due to this fact, top management was not satisfied with the situation. The performance of the company was measured after implementation of the proposed model. Surveys show that satisfaction and reliability of this process have been increased.

The main characteristics and innovations of the proposed model can be listed as below:

- Proposing a model which simultaneously accomplish supplier selection and order allocation,
- Determining criteria from strategic point of view,
- Considering multi-supplier, multi-criterion, and multi-part in the proposed model,
- Taking into account the internal and external criteria,
- Applying fuzzy logic to deal with uncertainty of human's opinions,
- Considering policies of the company (e.g., warehouse capacity).

In this article, inventory management costs such as holding cost and stock-out cost are not considered in the model. Further research can be conducted to offer quantitative model considering mentioned costs.

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Appendix 1

Convert the linguistic evaluations into TFN to construct the fuzzy decision matrix and determine the fuzzy weight of each criterion

Table 23 Fuzzy decision matrix and fuzzy weights of five suppliers (internal criteria, part 1)

Suppliers	Internal criteria			
	C_1	C_2	C_3	C_4
A_1	(2.50 4.50 6.50)	(3.50 5.50 7.25)	(6.50 8.00 9.00)	(5.50 7.50 8.75)
A_2	(4.25 6.00 7.50)	(3.50 5.50 7.50)	(4.25 5.75 7.25)	(6.00 7.75 9.00)
A_3	(3.50 5.50 7.50)	(3.00 5.00 7.00)	(6.00 7.50 8.50)	(5.50 7.50 9.00)
A_4	(5.00 7.00 8.50)	(4.50 6.25 7.75)	(3.50 5.50 7.25)	(2.00 4.00 6.00)
A_5	(7.50 9.25 10.00)	(5.00 7.00 8.75)	(3.25 4.75 6.25)	(2.75 4.50 6.50)
W	(0.432 0.685 0.877)	(0.495 0.725 0.875)	(0.345 0.575 0.790)	(0.275 0.520 0.750)

Table 24 Fuzzy decision matrix and fuzzy weights of five suppliers (external criteria, part 1)

Suppliers	External criteria				
	C_5	C_6	C_7	C_8	C_9
A_1	(4.00 6.00 7.75)	(2.75 4.50 6.25)	(5.00 6.75 8.00)	(6.50 8.00 9.00)	(5.00 7.00 8.50)
A_2	(4.00 6.00 7.50)	(7.00 8.75 9.75)	(4.50 6.50 8.25)	(4.75 6.50 8.00)	(3.75 5.25 6.75)
A_3	(5.50 7.25 8.50)	(6.75 7.75 8.25)	(5.25 6.75 8.00)	(4.50 6.55 8.25)	(6.50 8.00 9.00)
A_4	(3.75 5.25 6.75)	(2.00 4.00 6.00)	(6.50 8.25 9.50)	(6.50 8.25 9.50)	(4.50 6.50 8.25)
A_5	(6.50 8.25 9.25)	(7.00 8.75 9.75)	(5.00 7.00 8.50)	(5.75 7.00 7.75)	(5.50 7.25 8.50)
W	(0.255 0.445 0.715)	(0.113 0.243 0.445)	(0.197 0.360 0.605)	(0.203 0.333 0.545)	(0.340 0.550 0.803)

Table 25 Fuzzy decision matrix and fuzzy weights of five suppliers (internal criteria, part 2)

Suppliers	Internal criteria			
	C_1	C_2	C_3	C_4
A_1	(1.25 3.00 5.00)	(2.50 4.50 6.50)	(0.75 2.00 4.00)	(3.00 5.00 6.75)
A_2	(2.00 4.00 6.00)	(4.00 6.00 7.75)	(4.50 6.25 7.75)	(3.00 5.00 7.00)
A_3	(4.50 6.50 8.25)	(3.00 5.00 7.00)	(8.00 9.50 10.00)	(4.00 6.00 7.75)
A_4	(4.50 6.25 7.75)	(2.50 4.50 6.50)	(4.00 5.25 6.50)	(3.50 5.50 7.25)
A_5	(4.00 6.00 7.75)	(7.50 9.00 9.75)	(7.50 9.00 9.75)	(6.50 8.00 9.00)
W	(0.432 0.685 0.877)	(0.495 0.725 0.875)	(0.345 0.575 0.790)	(0.275 0.520 0.750)

Table 26 Fuzzy decision matrix and fuzzy weights of five suppliers (external criteria, part 2)

Suppliers	External criteria				
	C_5	C_6	C_7	C_8	C_9
A_1	(1.75 3.25 5.00)	(1.50 3.50 5.50)	(4.50 6.50 8.50)	(2.50 4.50 6.50)	(1.75 3.50 5.50)
A_2	(5.00 7.00 8.50)	(3.50 5.50 7.25)	(7.00 9.00 10.00)	(5.50 7.50 9.00)	(4.00 6.00 7.75)
A_3	(5.50 7.25 8.75)	(4.50 6.50 8.00)	(3.25 4.50 5.75)	(4.50 6.25 7.50)	(4.50 6.50 8.00)
A_4	(4.00 6.00 7.75)	(4.00 5.75 7.25)	(5.00 7.00 8.50)	(4.00 6.00 7.50)	(6.00 7.75 8.75)
A_5	(4.50 6.25 7.75)	(5.50 7.25 8.75)	(2.00 4.00 6.00)	(1.50 3.50 5.50)	(4.00 5.75 7.25)
W	(0.255 0.445 0.715)	(0.113 0.243 0.445)	(0.197 0.360 0.605)	(0.203 0.333 0.545)	(0.340 0.550 0.803)

Appendix 2

The distance of each supplier from FPIS and FNIS regarding each criterion for part 1 and 2

Table 27 Distances between A_i (i=1, 2,…, 5) and (A^+ and A^-) with respect to each criterion (part 1)

P_1	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
$d(A_1,A^+)$	0.5806	0.4094	0.3162	0.3444	0.4000	0.3120	0.3391	0.2666	0.3743
$d(A_2,A^+)$	0.4995	0.4072	0.4010	0.3337	0.4017	0.2417	0.3454	0.3030	0.4375
$d(A_3,A^+)$	0.5252	0.4347	0.3336	0.3443	0.3602	0.2537	0.3367	0.3042	0.3321
$d(A_4,A^+)$	0.4526	0.3652	0.4177	0.4666	0.4223	0.3217	0.3035	0.2635	0.3919
$d(A_5,A^+)$	0.3500	0.3342	0.4463	0.4431	0.3328	0.2417	0.3339	0.2895	0.3618

Table 28 Distances between A_i (i=1, 2,…, 5) and (A^+ and A^-) with respect to each criterion (part 1)

P_1	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
$d(A_1,A^-)$	0.2913	0.3159	0.4051	0.4012	0.2826	0.1559	0.2449	0.2528	0.3539
$d(A_2,A^-)$	0.3656	0.3271	0.2950	0.4154	0.2730	0.2635	0.2512	0.2118	0.2566
$d(A_3,A^-)$	0.3547	0.2950	0.3758	0.4106	0.3244	0.2229	0.2450	0.2192	0.3916
$d(A_4,A^-)$	0.4311	0.3553	0.2909	0.2446	0.2372	0.1476	0.3060	0.2691	0.3363
$d(A_5,A^-)$	0.5525	0.4161	0.2391	0.2705	0.3646	0.2635	0.2631	0.2085	0.3581

Table 29 Distances between A_i (i=1, 2,…, 5) and (A^+ and A^-) with respect to each criterion (part 2)

P_2	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
$d(A_1,A^+)$	0.5162	0.5448	0.6492	0.4288	0.4622	0.2901	0.3707	0.3307	0.4969
$d(A_2,A^+)$	0.4649	0.4599	0.4546	0.4265	0.3402	0.2533	0.3145	0.2594	0.3939
$d(A_3,A^+)$	0.3459	0.5148	0.3284	0.3915	0.3304	0.2377	0.4301	0.2864	0.3760
$d(A_4,A^+)$	0.3516	0.5448	0.4966	0.4097	0.3687	0.2487	0.3602	0.2927	0.3288
$d(A_5,A^+)$	0.3672	0.3014	0.3449	0.3232	0.3591	0.2257	0.4438	0.3596	0.4017

Table 30 Distances between A_i (i=1, 2,…, 5) and (A^+ and A^-) with respect to each criterion (part 2)

P_2	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
$d(A_1,A^-)$	0.2389	0.2822	0.1752	0.2652	0.1896	0.1373	0.2975	0.1996	0.2334
$d(A_2,A^-)$	0.3017	0.3695	0.3965	0.2752	0.3629	0.1893	0.3699	0.2979	0.3630
$d(A_3,A^-)$	0.4553	0.3143	0.5529	0.3173	0.3759	0.2128	0.1921	0.2438	0.3816
$d(A_4,A^-)$	0.4289	0.2822	0.3299	0.2911	0.3226	0.1908	0.3022	0.2482	0.4352
$d(A_5,A^-)$	0.4218	0.5393	0.5323	0.3964	0.3261	0.2352	0.1962	0.1632	0.3389

References

1. Vanteddu G, Chinnam RB, Gushikin O (2010) Supply chain focus dependent supplier selection problem. Int J Prod Econ 129(1):204–216
2. Zhang JL, Zhang MY (2010) Supplier selection and purchase problem with fixed cost and constrained order quantities under stochastic demand. Int J Prod Econ 129(1):1–7
3. Chang B, Chang CW, Wu CH (2010) Fuzzy DEMATEL method for developing supplier selection criteria. Expert Syst Appl 38(3):1850–1856
4. Amin SH, Razmi J (2009) An integrated fuzzy model for supplier management: a case study of ISP selection and evaluation. Expert Syst Appl 36(4):8639–8648
5. Chen YJ (2010) Structured methodology for supplier selection and evaluation in a supply chain. Inform Sci
6. Punniyamoorthy M, Mathiyalagan P, Parthiban P (2011) A strategic model using structural equation modeling and fuzzy logic in supplier selection. Expert Syst Appl 38(1):458–474
7. Sonmez M (2006) A review and critique of supplier selection process and practices. Loughborough University Business School occasional papers series, No. 2006:1
8. Keskin GA, Ilhan S, Özkan C (2010) The fuzzy ART algorithm: a categorization method for supplier evaluation and selection. Expert Syst Appl 37(2):1235–1240
9. Guo X (2009) Supplier selection based on hierarchical potential support vector machine. Expert Syst Appl 36:6978–6985
10. Sanayei A, Mousavi SF, Abdi MR, Mohaghar A (2008) An integrated group decision-making process for supplier selection and order allocation using multi attribute utility theory and linear programming. J Frankl Inst 345(7):731–774
11. Youssef MA, Zairi M, Mohanty B (1996) Supplier selection in an advanced manufacturing technology environment: an optimization model. Benchmarking Int J 3(4):60–72
12. Jain R, Singh A, Yadav H, Mishra P (2012) Using data mining synergies for evaluating criteria at pre-qualification stage of supplier selection. J Intell Manuf 1(1):1–11
13. Razmi J, Songhori MJ, Khakbaz MH (2009) An integrated fuzzy group decision making/fuzzy linear programming (FGDMLP) framework for supplier evaluation and order allocation. Int J Adv Manuf Technol 43(6–7):590–607
14. Chai J, Liu J, Ngai E (2013) Application of decision-making techniques in supplier selection: a systematic review of literature. Expert Syst Appl 40(10):3872–3885
15. Oliveira RC, Lourenço JC (2002) A multi-criteria model for assigning new orders to service suppliers. Eur J Oper Res 139(2):390–399
16. Aouam T, Randin R, Abrache J (2004) Robust strategies for natural gas procurement. Eur J Oper Res 205(1):151–158
17. Sepehri M (2012) Strategic selection and empowerment of supplier portfolios case: oil and gas industries in Iran. Procedia-Soc Behav Sci 74(29):51–60
18. Congjun R, Yong Z, Shihua M (2012) Procurement decision making mechanism of divisible goods based on multi-attribute auction. Electron Commer Res Appl 11(4):397–406
19. Igarashi M, De Boer L, Magerholm Fet A (2013) What is required for greener supplier selection? A literature review and conceptual model development. J Purch Supply Manag 19(4):247–263
20. Ho W, Xu X, Prasanta K, Dey PK (2010) Multi-criteria decision making approaches for supplier evaluation and selection: a literature review. Eur J Oper Res 202(1):16–24
21. Chen LS, Cheng CH (2005) Selecting IS personnel using ranking fuzzy number by metric distance method. Eur J Oper Res 160(3):803–820
22. Önut S, Kara S, Isik E (2009) Long term supplier selection using a combined fuzzy MCDM approach: a case study for a telecommunication company. Expert Syst Appl 36(2):3887–3895
23. Zeydan M, Colpan C, Cobanoglu C (2011) A combined methodology for supplier selection and performance evaluation. Expert Syst Appl 38(3):2741–2751
24. Lin CT, Chen CB, Ting YC (2011) An ERP model for supplier selection in electronics industry. Expert Syst Appl 38(3):1760–1765
25. Taguchi G (1986) Introduction to quality engineering: designing quality in to products and processes. Asian Productivity Organization, Tokyo
26. Amin SH, Razmi J, Zhang G (2011) Supplier selection and order allocation based on fuzzy SWOT analysis and fuzzy linear programming. Expert Syst Appl 38(1):334–342
27. Zadeh LA (1965) Fuzzy sets. Inf Control 8(2):338–353
28. Torlak G, Sevkli M, Sanal M, Zaim S (2010) Analyzing business competition by using fuzzy TOPSIS method: an example of Turkish domestic airline industry. Expert Syst Appl 38(4):3396–3406
29. Kaufmann A, Gupta MM (1991) Introduction to fuzzy arithmetic: theory and applications. Van Nostrand Reinhold, New York
30. Hwang CL, Yoon K (1981) Multiple attributes decision making methods and applications. Springer, Berlin
31. Shih HS, Syur HJ, Lee ES (2007) An extension of TOPSIS for group decision making. Math Comput Model 45(7–8):801–813
32. Sun C-C (2010) A performance evaluation model by integrating fuzzy AHP and fuzzy TOPSIS methods. Expert Syst Appl 37(12):7745–7754
33. Buyukozkan G, Feyziog˘lu O, Nebol E (2007) Selection of the strategic alliance partner in logistics value chain. Int J Prod Econ 113(1):148–158
34. Kuo MS, Tzeng G-H, Huang WC (2007) Group decision making based on concepts of ideal and anti-ideal points in fuzzy environment. Math Comput Model 45(3/4):324–339
35. Wang TC, Chang TH (2007) Application of TOPSIS in evaluating initial training aircraft under a fuzzy environment. Expert Syst Appl 33(4):870–880
36. Wang JW, Cheng CH, Huang KC (2009) Fuzzy hierarchical TOPSIS for supplier selection. Appl Soft Comput 9(1):377–386
37. Razmi J, Zairi M, Gunasekaran A (2006) The application of analytic hierarchy process in classification of material planning and control systems. Int J Serv Oper Manag 2(4):352–366