Supplier selection and order allocation based on fuzzy SWOT analysis and fuzzy linear programming

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A R T I C L E   I N F O

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SWOT (Strengths, Weaknesses, Opportunities and Threats)
Fuzzy logic
Linear programming

A B S T R A C T

Supplier selection is a multi criteria decision-making problem that comprises tangible and intangible factors. The majority of previous supplier selection techniques do not consider strategic perspective. Besides, uncertainty is one of the most important obstacles in supplier selection.

In this paper, quantified SWOT is applied in the context of supplier selection for the first time. SWOT (Strengths, Weaknesses, Opportunities and Threats) is one of the most well-known techniques for conducting a strategic study. In addition, the fuzzy logic and triangular fuzzy numbers are integrated with SWOT analysis – as a novel innovation – to deal with vagueness of human thought. SWOT analysis can consider both qualitative and quantitative criteria. The managers can understand the position of suppliers in a competitive environment with a glance at SWOT matrix. Moreover, a fuzzy linear programming model is proposed to determine how much should be purchased from each supplier. It is supposed that the demand is a fuzzy number. Besides, the capacity of warehouse is considered as a constraint. A case study is utilized concurrently to show the efficiency of the proposed model.

1. Introduction

Companies try to reduce costs and manage risks. It is important to know that one of the major portions of the firms’ expenses is related to logistics activities which mostly are more than 50% of all companies’ costs (Aissaoui, Haouari, & Hassini, 2007). Therefore, companies try to manage purchasing tasks. Experts believe that supplier selection is one of the most prominent activities of purchasing departments (Xia & Wu, 2007). But, supplier selection is a difficult problem for managers because the performances of suppliers are varied based on each criterion (Liu & Hai, 2005).

In the previous investigations, several methods have been suggested to solve the supplier selection problem. However, the most of them have not paid attention to the strategic perspective. SWOT (Strengths, Weaknesses, Opportunities and Threats) is a useful technique which is commonly known in strategic management area. SWOT analyzes the external opportunities and threats as well as the internal strengths and weaknesses. Besides, it is one of the most famous tools for strategy formulation. The goal of the analysis of external opportunities and threats is to evaluate whether a company can capture opportunities and avoid threats when facing an uncontrollable external environment such as change in the rule of law (Chang & Huang, 2006). SWOT can also be used when strategy alternative emerges and the relevant decision context needs to be analyzed (Christensen, Berg, & Salter, 1976). On the other hand, the majority of papers assume that the demand is deterministic, but in reality this assumption is not true (Snyder, 2006).

In this paper, we use quantified SWOT analysis as a decision tool to formulate strategic plans for supplier selection. To our knowledge, no one has applied SWOT analysis in supplier selection. Furthermore, fuzzy logic has been integrated with SWOT analysis to deal with vagueness and imprecision of human thought. The proposed decision model is more comprehensive and competitive rather than other published MCDM models for supplier selection due to its dynamic nature and strategic oriented. This model has been implemented in a company that manufactures automobile. The company intends to buy products from multiple supplies. Furthermore, we utilize a proposed fuzzy linear programming model to determine the order quantity from each supplier. In this model, demand is a fuzzy number. The output of SWOT analysis is applied as an input in the mathematical model. The majority of previous models suppose that there is a single product, but our model has been designed for multiple products. In addition, the capacity of warehouse is taken into account as a constraint.

The organization of this paper is as follows: Section 2 discusses the literature review. Fuzzy logic is presented in Section 3. In Section 4, a case study is illustrated. In the first phase, suppliers are assessed based on fuzzy SWOT analysis. Then, the order

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2. Literature review

Supplier selection is a multi criteria decision-making problem. Criteria and decision-making techniques are two important elements in a supplier selection problem. Dickson (1966) was one of the first ones in this field of study. He identified 23 different criteria for supplier selection based on a questionnaire sent to managers of companies of North America. These criteria include quality, delivery, performance, warranty and claim policy, production facilities and capacity, net price, and technical capabilities. Moore and Fearon (1973) presented a review where focused on industry applications of computer-assisted supplier selection models. Weber, Current, and Benton (1991) categorized the literature on supplier selection by reviewing 74 articles. They identified price, delivery, quality, facilities and capacity, geographic location, and technology capability. De Boer, Labro, and Morlacchi (2001) identified four stages in supplier selection problem which consist of problem formulation, formulation of criteria, qualification and final selection. They stated that the majority of authors have focused on final selection stage. Degraeve, Labro, and Roodhooft (2004) presented some published supplier selection models and compared their relative efficiency using the total cost of ownership. Aissaoui et al. (2007) have presented another literature review according to the purchasing process. Their proposed classification is based on single and multiple items and periods.

2.1. Supplier selection based on fuzzy logic

Uncertainty is one of the most challenging but important problems in SCM (Melo, Nickel, & Saldanha-da-Gama, 2009; Snyder, 2006). In order to solve the problem of ambiguity of the attributes’ outcomes in the realistic environment some researchers have used assorted methods based on fuzzy sets theory (FST) and fuzzy logic. Li, Fun, and Hung (1997) used fuzzy sets theory in supplier selection problem to consider imprecise data. Kwong, Ip, and Chan (2002) presented fuzzy expert system for supplier assessment; however, application of their proposed method is difficult in practice. Kahraman, Cebeci, and Ulukan (2003) utilized fuzzy analytical hierarchy process to select the best suppliers. Jain, Tiwari, and Chan (2004) evaluated the supplier performance using an evolutionary fuzzy-based approach and linguistic variables. Kumar, Vrat, and Shankar (2004, 2006) focused on fuzzy goal programming to solve a vendor selection problem. They minimized cost, rejections and late deliveries simultaneously. Bevilacqua, Ciarpica, and Giacchetta (2006) suggested a method that utilizes the house of quality concept for the supplier selection, but they ignored quantitative metrics. They used triangular fuzzy numbers. Bottani and Rizzi (2006) presented a fuzzy approach for the selection of the most suitable 3PL service provider. They applied fuzzy TOPSIS. Chou and Chang (2008) presented a fuzzy multi attribute rating technique approach for solving the vendor selection problem from the perspective of strategic management. They utilized triangular fuzzy numbers; however, the model does not regard external criteria such as opportunities and threats. Amin and Razmi (2009) proposed an integrated model which covers supplier selection, evaluation and development stages. Besides, they applied a fuzzy-based algorithm for selecting the best Internet service provider (ISP). In other words, they examined the supplier selection in service environments. The most of above literature has discussed the strengths and weaknesses of the suppliers without considering the external attributes and strategic perspective. In the proposed method it will be illustrated that how the SWOT method can be applied to respond this shortage.

2.2. Supplier selection and order lot sizing

Some authors not only solve the supplier selection problem, but also they determine how much should be purchased from each selected supplier. The majority of these papers have written in manufacturing environments. Ghodsypour and O’Brien (1998) combined analytical hierarchy process (AHP) and linear programming to consider both tangible and intangible factors in supplier selection problem. However, their model is deterministic and does not consider uncertainty in human though. In this paper, we extend their model. Weber, Current, and Desai (2000) utilized DEA for evaluating the suppliers and multi-objective programming for determining the vendor order quantity. Kim, Leung, Taepark, Zhang, and Lee (2002) considered a supply network consisting of a manufacturer and its suppliers. They formulated a nonlinear programming model and determined how much of each raw material and component part to order from which supplier according to the capacity of suppliers and manufacturer. It is assumed that demand is stochastic. However, they only determined the order quantity and they did not select the suppliers. Liao and Rittscher (2007) proposed a multi-objective supplier selection model under stochastic demand conditions. Stochastic supplier selection has been determined with simultaneous consideration of the cost, quality, delivery and flexibility according to the limitations of capacity. Xia and Wu (2007) presented a new method based on analytical hierarchy process improved by rough sets theory and multi-objective to determine the number of suppliers and the order quantity allocated to these suppliers. In addition, they considered discount. Wadhwa and Ravindran (2007) optimized Price, lead-time and rejects (quality) to select the best vendor in the field of outsourcing. They applied quantity discount in the model. Faez, Chodsypour, and O’Brien (2009) proposed vendor selection and order allocation using an integrated fuzzy case-based reasoning and mix integer programming model. However, they did not examine strategic issues in the process of supplier selection. Demirtas and Ustun (2008) presented integrated approach of analytic network process (ANP) and multi-objective linear programming for selecting the best suppliers. The main purpose of integrated models is to consider both qualitative and quantitative criteria. According to these papers, most of authors have used multi-objective programming for lot sizing.

2.3. SWOT

SWOT is a management tool to formulate strategic action plans. Christensen et al. (1976) developed the SWOT analysis on the basis of Grand Strategy Matrix (GSM). SWOT is an acronym for strengths, weaknesses, opportunities and threats. It involves specifying the objective of the business venture or project and identifying the internal and external factors that are favorable and unfavorable for achieving that objective. SWOT maximizes strengths and opportunities, and minimizes threats and weaknesses. In other words, it transforms weaknesses into strengths, and threats into opportunities (Arslan & Deha Er, 2008; Christensen et al., 1976). Kurttila, Pesonen, Kangas, and Kajanansu (2000) presented a new hybrid method for improving the usability of SWOT analysis. They combined SWOT and analytic hierarchy process (AHP) to provide information for strategic planning processes. Chang and Huang (2006) also suggested the quantified SWOT analytical method which was adapted to the concept of Multiple-Attribute Decision Making. They used AHP and a multi-layer scheme to simplify complicated problems. They performed SWOT analysis on several enterprises concurrently. It is well known that through AHP, the
decision maker is only asked to give judgments about either the relative importance of one criterion against another or its preference of one candidate on one criterion against another. However, when the number of candidates and criteria grows, the pairwise comparison process becomes cumbersome, and the risk of generating inconsistencies grows. In addition, AHP, like many systems which work based on pairwise comparisons, can produce “rank reversal” results (Dyer, 1990). Yuksel and Dag deviren (2007) proposed analytical network process (ANP) in a SWOT analysis. However, the problems of pairwise comparisons are remained. In this paper, the SWOT method has been used to analyze the current situation of the suppliers in the competitive market according to strategic viewpoint.

3. Fuzzy logic

A fuzzy set is a class of objects with grades of membership. A membership function is between zero and one (Zadeh, 1965). Fuzzy logic is derived from fuzzy set theory to deal with reasoning that is approximate rather than precise. It allows the model to easily incorporate various subject experts’ advice in developing critical parameter estimates (Zimmermann, 2001). In other words, fuzzy logic enables us to handle uncertainty.

There are some kinds of fuzzy numbers. Among the various shapes of fuzzy number, triangular fuzzy number (TFN) is the most popular one. It is represented with three points as follows:

$$A = (a_1, a_2, a_3)$$

The membership function is illustrated in Fig. 1. Let A and B are defined as

$$A = (a_1, a_2, a_3), B = (b_1, b_2, b_3).$$

Then

$$C = (a_1 + b_1, a_2 + b_2, a_3 + b_3)$$

is the addition of these two numbers. Besides,

$$D = (a_1 - b_1, a_2 - b_2, a_3 - b_3)$$

is the subtraction of them. Moreover,

$$E = (a_1 b_1, a_2 b_2, a_3 b_3)$$

is the multiplication of them (Klir & Yuan, 1995; Lai & Hwang, 1995; Zimmermann, 2001).

$$\mu_A(x) = \begin{cases} 1, & \text{for } x < a_1 \\ \frac{x-a_1}{a_2-a_1}, & \text{for } a_1 \leq x < a_2 \\ \frac{x-a_2}{a_3-a_2}, & \text{for } a_2 \leq x < a_3 \\ 0, & \text{for } x > a_3 \end{cases}$$

4. Case study

S.G. Company has been established in 1985 as a designing, engineering and supplying company of auto parts but it practically commenced its activities in 1989. This company is a pioneer in supply chain management of auto parts in Iran. S.G. Company supplies the necessary parts of 400,000 automobiles per year for assembly plants, and is planning to increase the production to 500,000 vehicles per year. Its 23 years of efforts and endeavor have led to the formation of a network of the capable automobile parts suppliers. The services offered by S.G. Company and its main responsibility and strategies are as follows:

- To provide supply planning or localization planning (produce parts in the country).

- To identify potential auto-parts manufacturers and to evaluate them.

- To sign supply contracts with auto-part manufacturers or vendors.

- To control the quality of parts.

- To train auto-part manufacturers in order to promote their technical and managerial knowledge.

- To promote and facilitate auto-part export (including joint investment projects, marketing, and commercial services).

Recently, the company is investigated to produce a new automobile. Therefore, the ability and capacity of suppliers should be evaluated. Up to know the majority of manufactured automobiles were sold in Iran. However, in recent years, the quality of products has increased and the final costs have decreased. Thus, the manufacturers plan to export automobiles. The traditional assessment system implies on the internal factors such as cost and quality. But, other factors like mutual trust should be added to shift from national to international market. The S.G. Company divides the parts suppliers into several groups based on the products and collects the necessary information in a data base. Tire suppliers are one of the groups. Wheels and tires are famous components of each vehicle. Nowadays, more than one billion tires are produced every year in the world with the three leading tire manufacturers absorbing more than 60% of a global market share. China, India, Japan, Hong Kong and Thailand are the most well-known manufacturers of tires in the global market. Tiers of automobiles are usually rubber tubes or more specifically pneumatic enclosures affixed around a wheel which facilitate rotation of a vehicle. Almost all types of automobiles ranging from two wheelers, cars, to airplanes use tires. Tires are filled with air, which provides a flexible support to the vehicle. Tires enhance the performance of an automobile by providing a comfortable grip of the road. Tires often are manufactured using ductile elastomer material like fabric, rubber and wire. The company wants to purchase two types of passenger car tires. In other words, there are two products in this case study.

The top management forms a project team. The main purposes of the team are identifying eligible candidates and defining the appropriate criteria, and selecting the best supplier, and ultimately determining the order quantity. The team works under supervision of the head of logistics. Moreover, three experts from purchasing department, logistics department, and information Technology department contribute in decision-making process. Furthermore, two academicians from universities participate in the sessions as consultants. The team is obligated to select the suppliers who produce the parts in the country.

The proposed method is composed of two sections. In the first phase fuzzy SWOT analysis is applied to evaluate the suppliers. The output of this stage is the weight of each supplier. In the second phase, a fuzzy linear programming model is proposed to determine how much should be purchased from each supplier.

4.1. Phase 1: supplier evaluation

This section describes the proposed model to evaluate suppliers. The case study will be progressed simultaneously.

Step 1: List qualified suppliers: In the first step, it is necessary to select a set of suppliers. The members of committee arranged some meetings and decided to publish an advertisement in newspapers to identify the tier suppliers who are interested to contribute in the project. The team announced minimum requirements such as financial ability to filter small and local suppliers. After pre assessment of all existent suppliers (10), five suppliers have been chosen as the best candidates.

\[ \text{Fig. 1. A triangular fuzzy number.} \]
**Step 2:** Research and draft the key factors of internal and external criteria for supplier selection: the key factors consist of both benefit and cost metrics. The academics collected a list of metrics that have been utilized frequently in international scientific journals. The team reviews the list in several meetings to select suitable criteria for supplier selection process. These criteria comprise both qualitative and quantitative ones. Finally, they determined the appropriate criteria by brainstorming. Fig. 2 shows the selected criteria. In the previous methods, external criteria were ignored, but SWOT enables us to take into account opportunities and threats.

**Step 3:** Determine the weights of qualified criteria for each supplier using linguistic variables: In this step ask the experts to determine the weights by linguistic variables for all criteria.

In this study the proposed scale of Amin and Razmi (2009) is applied to consider the uncertainty in human thought. Let $U = \{VL, L, ML, M, MH, H, VH\}$ be the linguistic set used to express opinions on the group of attributes ($VL = \text{Very Low, } L = \text{Low, } ML = \text{Medium Low, } M = \text{Medium, } MH = \text{Medium High, } H = \text{High, } VH = \text{Very High}$). The linguistic variables of $U$ can be quantified using triangular fuzzy numbers as: $VL = (0,0,1)$; $L = (0,1,3)$; $ML = (1,3,5)$; $M = (3,5,7)$; $MH = (5,7,9)$; $H = (7,9,10)$; $VH = (9,10,10)$ (please refer to Fig. 3). Three decision makers established the level of importance or weight of each of criteria by brain storming. Fig. 2 shows the selected criteria.

**Step 4:** Collect the required data for the quantified attributes such as unit cost and delay which have been highlighted by “QN”. This information is obtained by special forms which have been sent to the candidates. Table 2 shows the results. The results have been shown in Table 2.

![Defuzzified triangular fuzzy number](image)

**Step 5:** Calculate the weights of criteria by linguistic variables: The importance of each criterion is different. Therefore, the decision makers should determine the priorities between criteria. The supervisor of project was implied to devote enough time to this step. As a result, the three experts dedicated several hours to determine the weights. The results are illustrated in Table 3.

**Step 6:** Normalize the scores by Eqs. (3) and (4): the purpose of normalization is to unify the scales of the key factors. After that, total weighted value can be obtained by multiplying the weights of criteria with normalized scores for each product. Then, determine the benchmarking value for the overall external and internal factors. In this study, the benchmarking value is defined as the average of total weighted values.

_Supplier Selection Criteria_

**Benefit**
- Quality
- Percent of on-time delivery
- Management stability

**Cost**
- Unit cost

**External criteria**
- Mutual trust
- Strength of geographical location
- International communication

**Fig. 2.** Supplier selection hierarchies.
Cost-criteria normalization:

\[ f_{ij} = \min_{j=1,2,\ldots,m} \frac{w_{i}}{w_{ij}}, \quad i = 1, 2, \ldots, n, \quad e = 1, 2, \ldots, s, \]

Step 7: Calculate the coordinated values for each supplier by Eqs. (5) and (6), and compare the results. Then, demonstrate these values on the four-quadrant coordinate: firstly, the benchmarking value is subtracted from total weighted scores. The final value will be the coordinated value of the compared supplier in the SWOT matrix. The 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.

\[ IC_{ij} = I_{ij} - IB_{i}, \quad i = 1, 2, \ldots, n, \quad j = 1, 2, \ldots, m \]

\[ EC_{ij} = E_{ij} - EB_{i}, \quad i = 1, 2, \ldots, n, \quad j = 1, 2, \ldots, m \]
As it can be seen from Fig. 4, suppliers A3 and A4 are located in the quarter of strengths and facing threats from other competitors. The figure shows the position of suppliers in the competition. The figure can help the manager of the company to evaluate suppliers very well. The algorithm is used to compare the internal assessment of the suppliers; the other is the coordinated value used to compare the external assessment of the suppliers. Now each supplier has two groups of data: one is the external total weighted value of the jth supplier for product i, and EBi is the benchmarking value of the external assessment for product i.

By calculating the benchmarking and coordinated values according to the above formulas, two groups of data can be obtained: one is the coordinated value used to compare the internal assessment of the suppliers; the other is the coordinated value used to compare the external assessment of the suppliers. Now each supplier has coordinates of x and y, therefore its position in the competition can be clearly depicted. It is important that each x and y is defined for each product. After drawing the SWOT matrix, the most suitable suppliers can be selected by comparing suppliers’ position in the matrix. It is well known that the position in the quarter of strengths and opportunities is the most suitable position in this figure.

The members of team followed the steps 6 and 7 and performed the algorithm. The results are written in Tables 4 and 5. Besides, Fig. 4 shows the position of suppliers in the competition. The figure can help the manager of company to evaluate suppliers very quickly. As it can be seen from Fig. 4, suppliers A3 and A4 are located in the first quadrant. It means that these two suppliers have external opportunities for development and potentially have internal competing strength to get the opportunities. Therefore, it can be concluded that they are in the best position for facing competition. Suppliers A1, A2, and A5 (in the third quadrant) has low competitive strength and facing threats from other competitors.

### 4.2. Phase 2: order quantity

In the next phase of supplier selection, the order quantity should be determined. In this section, we propose a mathematical model (linear programming) to determine how much should be purchased from each supplier. In the majority of papers in the field of supplier selection, the order quantity is determined for a single item. However, we assume that each supplier produces multiple products. In addition, it is supposed that the demand is a fuzzy number.

#### 4.2.1. Notations

**Decision variable**

\[ x_{ij} \quad \text{the amount of product } i \text{ (} i = 1, 2, \ldots, n \text{) purchased from supplier } j \text{ (} j = 1, 2, \ldots, m \text{)} \]

**Model parameters**

- \( x_1 \): weight of internal criteria
- \( x_2 \): weight of external criteria
- \( I_{ij} \): internal total weighted value for product i and supplier j from SWOT analysis
- \( E_{ij} \): external total weighted value for product i and supplier j from SWOT analysis
- \( D_i \): fuzzy demand for the product i
- \( v_j \): capacity of supplier j for product i
- \( t_j \): minimum purchase quantity of product i from supplier j according to the purchasing

### Table 4

<table>
<thead>
<tr>
<th>Total weighted values (Quantitative: QN, Qualitative: QL).</th>
<th>Weights of criteria</th>
<th>Product i</th>
<th>Normalized scores</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A1</td>
<td>A2</td>
</tr>
<tr>
<td>Internal criteria</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit cost (QN)</td>
<td>0.33</td>
<td>1</td>
<td>1.000</td>
</tr>
<tr>
<td>Quality (QL)</td>
<td>0.27</td>
<td>1</td>
<td>0.923</td>
</tr>
<tr>
<td>Percent of on-time delivery (QN)</td>
<td>0.21</td>
<td>1</td>
<td>0.667</td>
</tr>
<tr>
<td>Management stability (QL)</td>
<td>0.19</td>
<td>1</td>
<td>0.875</td>
</tr>
<tr>
<td>Internal total weighted values</td>
<td></td>
<td>1</td>
<td>0.795</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>0.769</td>
</tr>
<tr>
<td>External criteria</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mutual trust (QL)</td>
<td>0.21</td>
<td>1</td>
<td>0.581</td>
</tr>
<tr>
<td>Strength of geographical location (QL)</td>
<td>0.46</td>
<td>1</td>
<td>0.714</td>
</tr>
<tr>
<td>International communication (QL)</td>
<td>0.33</td>
<td>1</td>
<td>0.531</td>
</tr>
<tr>
<td>External total weighted values</td>
<td></td>
<td>1</td>
<td>0.626</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>0.626</td>
</tr>
</tbody>
</table>

### Table 5

<table>
<thead>
<tr>
<th>Coordinated values under the SWOT analysis.</th>
<th>Suppliers</th>
<th>Benchmarking value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A1</td>
<td>A2</td>
</tr>
<tr>
<td>Internal total weighted value for product 1</td>
<td>0.795</td>
<td>0.631</td>
</tr>
<tr>
<td>Internal total weighted value for product 2</td>
<td>0.769</td>
<td>0.626</td>
</tr>
<tr>
<td>Internal coordinated value for product 1</td>
<td>−0.004</td>
<td>−0.168</td>
</tr>
<tr>
<td>Internal coordinated value for product 2</td>
<td>−0.030</td>
<td>−0.174</td>
</tr>
<tr>
<td>External total weighted value for product 1</td>
<td>0.626</td>
<td>0.639</td>
</tr>
<tr>
<td>External coordinated value for product 1</td>
<td>−0.121</td>
<td>−0.108</td>
</tr>
<tr>
<td>External coordinated value for product 2</td>
<td>−0.121</td>
<td>−0.108</td>
</tr>
</tbody>
</table>
4.2.2. Mathematical model

$$\text{Max} \sum_{i=1}^{n} \sum_{j=1}^{m} (x_{ij} E_{ij} + x_{ij} D_{ij})$$

s.t. \[ \sum_{j=1}^{m} x_{ij} = D_{ij} \quad \forall i \]

\[ x_{ij} \leq v_{ij} \quad \forall i, j \]

\[ t_{ij} = x_{ij} \quad \forall i, j \]

\[ x_{1} + x_{2} = 1 \]

\[ \sum_{j=1}^{m} \sum_{i=1}^{n} d_{ij} x_{ij} \leq \sum_{i=1}^{n} b_{i} \]

\[ x_{ij} \geq 0, \quad i = 1, 2, \ldots, n, \quad j = 1, 2, \ldots, m \]

Table 6

<table>
<thead>
<tr>
<th>Supplier</th>
<th>$V_{ij}$</th>
<th>$t_{ij}$</th>
<th>$d_{i}$</th>
<th>$d_{j}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$i = 1$</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>1</td>
<td>200</td>
<td>250</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>300</td>
<td>400</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>500</td>
<td>500</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>580</td>
<td>650</td>
<td>1000</td>
<td>860</td>
</tr>
<tr>
<td>5</td>
<td>800</td>
<td>800</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

4.2.3. Solution

In this paper, the method of Verdegay (1982) is applied to solve the fuzzy linear programming model. The general model of linear programming with fuzzy resources is formulated as:

$$\text{Max} = cx$$

s.t. \[ (Ax)_{i} \leq b_{i}, \quad i = 1, 2, \ldots, m \] \[ x \geq 0 \] \[ (14) \]

Verdegay (1982) considered that if the membership functions of the fuzzy constraints are continuous, then Eq. (14) is equivalent of Eq. (15). Then, it is equivalent to parametric programming, while $\theta = 1 - \alpha$. Besides, $p_{i}$ is the maximum tolerance from $b_{i}$ and determined by decision maker. Therefore, the fuzzy linear programming problem given by Eq. (15) is equivalent to crisp linear programming model.

$$\text{Max} = cx$$

s.t. \[ (Ax)_{i} \leq b_{i} + (1 - \alpha)p_{i} \quad \forall i \]

\[ x \geq 0 \quad \text{and} \quad \alpha \in [0, 1] \]

$$\mu_{i}(x) = \begin{cases} 
1 & \text{if} \quad (Ax)_{i} < b_{i} \\
1 - \frac{|(Ax)_{i} - b_{i}|}{p_{i}} & \text{if} \quad b_{i} \leq (Ax)_{i} \leq b_{i} + p_{i} \\
0 & \text{if} \quad (Ax)_{i} > b_{i} + p_{i} 
\end{cases}$$

The formulation of the case study is written in this section. Table 6 shows the input data. After organizing a meeting, the members of committee decide $x_{1} = 4/7$ and $x_{2} = 3/7$. They interpreted that there are seven criteria which consist of four internal criteria and three external ones. In addition, in the previous section we calculated total weighted value of internal and external criteria by SWOT analysis. These results are utilized as input data.

Table 7

<table>
<thead>
<tr>
<th>$\theta$</th>
<th>$D_{1}$</th>
<th>$D_{2}$</th>
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<th>$X_{13}$</th>
<th>$X_{14}$</th>
<th>$X_{15}$</th>
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<td>100</td>
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<td>500</td>
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<tr>
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<td>1032</td>
<td>100</td>
<td>0</td>
<td>500</td>
<td>580</td>
<td>20</td>
<td>100</td>
<td>500</td>
<td>432</td>
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</tbody>
</table>
The manufacturer is working with supplier 1 for a long time. Moreover, supplier 1 is one of the key suppliers for automobile components. According to the strategic view point, the company prefers to buy at least 100 units of product 1 and 100 units of product 2 from supplier 1. This preference is taken into account by two constraints. In addition, according to the previous statistics, it is supposed that \( p_1 = 200 \) and \( p_2 = 172 \).

This problem can be solved by using of Solver in Microsoft Excel. The solver of Excel is a suitable package for solving linear programming models. Besides, using of this software is easy for practitioners. The results of the proposed model are illustrated in Table 7. It can be inferred from the Table that the company purchases products from suppliers 1, 3 and 4. The only exception is for \( \theta = 1 \) that the company have to purchase from suppliers 1, 3, 4, and 5.

\[
\begin{align*}
\text{Max} & \quad \frac{4}{7} \times (0.795x_{11} + 0.631x_{12} + 1x_{13} + 0.841x_{14} + 0.728x_{15} \\
& + 0.769x_{31} + 0.626x_{22} + 0.987x_{23} + \\
& + 0.871x_{24} + 0.745x_{25}) + \left(\frac{3}{7}\right) \times (0.626x_{11} + 0.639x_{12} \\
& + 0.966x_{13} + 0.778x_{14} + 0.727x_{15} \\
& + 0.626x_{31} + 0.639x_{22} + 0.966x_{23} + 0.778x_{24} + 0.727x_{25})
\end{align*}
\]

s.t. \( g_1(x) = x_{11} + x_{12} + x_{13} + x_{14} + x_{15} = 1000 + 200\theta \)

\( g_2(x) = x_{21} + x_{22} + x_{23} + x_{24} + x_{25} = 860 + 172\theta \)

\( x_{11} \geq 200, \quad x_{12} \leq 250, \quad x_{11} \leq 100 \)

\( x_{31} \geq 100, \quad x_{22} \leq 400, \quad x_{12} \leq 100 \)

\( x_{13} \leq 500, \quad x_{23} \leq 500 \)

\( x_{14} \leq 580, \quad x_{24} \leq 650 \)

\( x_{15} \geq 800, \quad x_{25} \leq 800 \)

\[4 \times (x_{11} + x_{12} + x_{13} + x_{14} + x_{15}) + 6 \times (x_{21} + x_{22} + x_{23} + x_{24} + x_{25}) \leq 11500\]

\[x_i \geq 0, \quad i = 1, 2, \quad j = 1, 2, 3, 4, 5\]

\(
\begin{align*}
\mu_1(x) &= \begin{cases} 
1 & g_1(x) < 1000 \\
1 - \frac{g_1(x) - 1000}{200} & 1000 \leq g_1(x) \leq 1200 \\
0 & g_1(x) > 1200
\end{cases} \\
\mu_2(x) &= \begin{cases} 
1 & g_2(x) < 860 \\
1 - \frac{g_2(x) - 860}{12} & 860 \leq g_2(x) \leq 1032 \\
0 & g_2(x) > 1032
\end{cases}
\end{align*}
\)

5. Discussion

Suppose that the manager of supplier A₁ has revised his policy and he has paid attention to the International communication (E₁) as a critical factor. We want to examine the effects of this decision on the market and analyze the changes for the product 1. Therefore, three decision makers devote fuzzy numbers to this criterion for the supplier A₁. By fixing other information, the problem has been resolved and the results have been written in Table 8. In addition, the matrix of SWOT has been shown in Fig. 5. It can be inferred from the figure that not only the situation of supplier A₁ has been altered in the competitive market, but also it makes change the condition of other suppliers particularly supplier A₄. Because supplier A₄ had received the highest score. However, the score of supplier A₁ increased and became the highest score. Considering the dynamic and competitive environment is the most important advantages of this method.

6. Conclusions

Supplier selection is a multi criteria decision-making problem, which includes both qualitative and quantitative factors. In this paper, we proposed a decisional model for supplier selection which consists of two phases. In the first phase, quantified SWOT analysis (Strengths, Weaknesses, Opportunities and Threats) is applied for evaluating suppliers. The linguistic variables and triangular fuzzy numbers are used to quantify variables. In the second phase, a fuzzy linear programming model is applied to determine the order quantity. The major novel points and merits of the proposed model are in fivefold: first, the model analyzes the supplier selection problem from strategic view point. Second, fuzzy logic has been applied because it can take into account uncertainty in humans’ opinions. Besides, it is assumed that demand is a fuzzy number. Third, fuzzy logic and quantitative SWOT have been composed for the first time. Fourth, both of quantitative and qualitative factors have been considered. Fifth, the capacity of warehouse and minimum order quantity are taken into account as constraints in the mathematical model. This algorithm can be easily implemented with a spreadsheet package and its computation is fast. Therefore, the proposed model can be applied easily in practical situations.

Not only the proposed fuzzy SWOT analysis can be applied for evaluating suppliers, but also it can be utilized for what De Boer et al. (2001) stated as a pre-qualification of suitable suppliers.

<table>
<thead>
<tr>
<th>International communication</th>
<th>DM₁</th>
<th>DM₂</th>
<th>DM₃</th>
<th>Weight</th>
<th>Defuzzifying</th>
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<td>A₁</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A₂</td>
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<td>A₄</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Table 8

Revised coordinated values of suppliers under the SWOT analysis for product 1.

<table>
<thead>
<tr>
<th>Suppliers</th>
<th>Benchmarking value</th>
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</thead>
<tbody>
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<td>A₁</td>
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<tr>
<td>A₂</td>
<td>0.631</td>
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<tr>
<td>A₃</td>
<td>1.000</td>
</tr>
<tr>
<td>A₄</td>
<td>0.841</td>
</tr>
<tr>
<td>A₅</td>
<td>0.728</td>
</tr>
</tbody>
</table>

Fig. 5. Revised matrix of the SWOT analysis.
The pre-qualification is defined as the process of reducing the set of all suppliers to a smaller set of acceptable ones. After drawing a quantified SWOT matrix, the manager of company can choose a pool of suppliers from the first quadrant of SWOT matrix. In the case study, suppliers A3 and A4 would be selected.

Expertise, experience, authority, and the responsibilities of decision makers are not equal in practice. Further research may be the determination of DMs, weights. Furthermore, in the mathematical model, the weights of internal and external criteria are determined by decision makers. It is useful to propose a scientific method for determining these weights. In addition, this paper has focused on manufacturing environment. It is worthwhile to implement fuzzy SWOT to select suppliers in service industries and compare the results. Moreover, we assumed that demand is a fuzzy number. Another future research may be the proposing mathematical model with stochastic and robust parameters.

References