



A Fuzzy Approach for Supplier Selection in a Supply Chain Management

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Abstract

In a broad sense, supply chain management is the concern in optimizing customer service level requirements along with optimizing the cost of steps involved in it. Since various sources of uncertainty and complex relationships between various entities exist in Supply Chain, managing a supply chain is a very difficult process. Consequently, determining suitable suppliers in the supply chain has become a key strategic subject during past years. In general, many quantitative and qualitative factors such as price, quality, flexibility and delivery performance should be considered for determining suitable suppliers. In this paper, linguistic values are used to assess the ratings and weights for these factors. A hierarchical multiple criteria decision-making model based on fuzzy sets theory with TOPSIS concept is used to deal with the supplier selection problems in the supply chain. In the end, a hypothetical example is shown to highlight the process of the mentioned method above.

Keywords: Fuzzy set theory, Linguistic variables, MCDM , Supplier selection, Supply chain

Introduction

A supply chain (SC) is an integrated process where a number of business entities (including suppliers, manufacturers, distributors, and retailers) work together to convert raw materials into the specified finished products and deliver these finished products to retailers or customers [1]. Figure 1 shows this material flow in a supply chain.

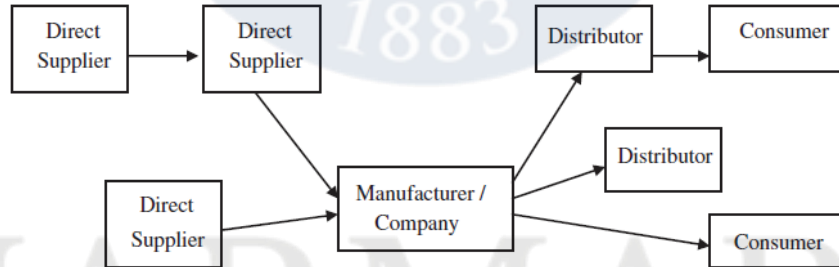


Figure 1. Material Flow in a Supply Chain [2]

Supply chain management and the supplier selection process have taken considerable attention in the business-management literature recently. Many manufacturers looked for to cooperate with their suppliers to be able to upgrade their management performance and competitiveness during the 1990s [3]. Business enterprises are forced to improve their supply chains to reduce inventory cost and develop customer service levels by reason of the increasing competition in today's global market. If ever a supplier becomes part of a well-managed and established supply chain, this relationship will have a lasting effect on the competitiveness of the entire supply chain. Therefore, the supplier selection problem has become one of the most important issues for establishing an effective supply chain system. The overall objective of supplier selection process is to reduce purchase risk, maximize overall value to the purchaser, and build the closeness and long term relationships between buyers and suppliers [4].

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In supply chains, coordination between a manufacturer and suppliers is naturally a difficult and important link in the channel of distribution. Many models developed for supplier selection decisions are based on rather simplistic perceptions of decision-making process [5] [6]. Most of these methods do not look like to address the complex and unstructured nature and context of many present day purchasing decisions [5]. According to the broad literature on supplier selection [5], [7], [8] we can come to a decision that decision-making is often influenced by uncertainty in practice. An increasing number of supplier decisions can be characterized as dynamic and unstructured [9]. Situations are changing rapidly or are uncertain and decision variables are difficult or impossible to quantify [10]. From the literature it can be concluded that in supplier selection the classic concept of “optimality” may not always be the most appropriate model [5]. We can conclude that supplier selection may involve several and different types of criteria, combination of different decision models, group decision-making and various forms of uncertainty. It is difficult to find the best way to evaluate and select supplier, and companies use a variety of different methods to deal with it. Therefore, the most important issue in the process of supplier selection is to develop a suitable method to select the right supplier.

In essential, the supplier selection problem in supply chain system is a group decision-making under multiple criteria. The degree of uncertainty, the number of decision makers and the nature of the criteria have to be taken into account in solving this problem. In classical MCDM methods, the ratings and the weights of the criteria are known precisely [11]. Technique for Order Performance by Similarity to Ideal Solution (TOPSIS), one of the known classical MCDM methods, may provide the basis for developing supplier selection models that can effectively deal with these properties. It bases upon the concept that the chosen alternative should have the shortest distance from the Positive Ideal Solution (PIS) and the farthest from the Negative Ideal Solution (NIS). In addition to this, under many conditions, data is inadequate to model real-life situations. Since human judgements including preferences are often uncertain and cannot estimate its preference with an exact numerical value, a more realistic approach can use linguistic assessments instead of numerical values. In other words, the ratings and weights of the criteria in the problem are assessed by means of linguistic variables [11], [12], [13], [14], [15]. In this paper, considering the fuzziness in the decision data and group decision-making process, linguistic variables are used to assess the weights of the each criteria and the ratings of each alternative with respect to each criterion. According to the concept of TOPSIS, the fuzzy positive ideal solution (FPIS) and the fuzzy negative ideal solution (FNIS) are calculated. And then, a vertex method is applied to find out the distance between two fuzzy ratings. Using the vertex method, the distance of each alternative from FPIS and FNIS can be calculated, respectively. Finally, a closeness coefficient of each alternative is defined to determine the ranking order of all alternatives. The higher value of closeness coefficient indicates that an alternative is closer to FPIS and farther from FNIS simultaneously. This paper is arranged as follows: Next section introduces the basic definitions and notations of the fuzzy set theory. In Section 3, the algorithm of a fuzzy decision-making method with TOPSIS concept is given, and its adapted to cope with the supplier selection problem. And then, the proposed method is illustrated with a hypothetical example by Section 4. Finally, conclusions are pointed out at the end of this paper, by Section 5.

Fuzzy Set Theory

Zadeh, whom presented fuzzy set theory, stated that using linguistic expressions are necessary to solve the problems noninclusive of certainty and to express human thought [16] [17]. Many uncertainty came upon in daily life can not be modelled by certainty approach, but fuzzy sets can do this by modelling. Fuzzy set theory enhances to express this uncertainty with mathematically by fuzzy numbers while modelling the linguistic uncertainty about human sense and special judgements. Due to the providing operation easiness, the commonly used fuzzy number type is triangular fuzzy numbers. A triangular fuzzy number is shown in the form of “ n ” (n_1, n_2, n_3). Let m and n be positive fuzzy numbers, r a positive real number, m_1^α and n_1^α be the upper limit of closed interval; and $m^\alpha = [m_1^\alpha, m_u^\alpha]$, $n^\alpha = [n_1^\alpha, n_u^\alpha]$ the α cut of two fuzzy number. The elementary operations worked with triangular fuzzy numbers can be summarized as follows [17]:



$$(m(+))n^{\alpha} = [m_1^{\alpha} + n_1^{\alpha}, m_u^{\alpha} + n_u^{\alpha}] \quad (1)$$

$$(m(-))n^{\alpha} = [m_1^{\alpha} - n_u^{\alpha}, m_u^{\alpha} - n_1^{\alpha}] \quad (2)$$

$$(m(.))n^{\alpha} = [m_1^{\alpha} \cdot r, m_u^{\alpha} \cdot r] \quad (3)$$

Vertex method, is a method used to find the distance between fuzzy numbers. The distance between two fuzzy numbers such as $m = (m_1, m_2, m_3)$ and $n = (n_1, n_2, n_3)$ calculated with vertex method is as follows [17]:

$$d(m,n) = \sqrt{\frac{1}{3}[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2]} \quad (4)$$

Fuzzy TOPSIS Method

One of the most common methods used in MCDM problems is TOPSIS method, first suggested in 1981 [18]. The most important feature of this method as a linear weighting technique is identifying the solution which has the shortest geometric distance from the positive ideal solution and the farthest geometric distance from the negative ideal solution. By calculating these two-way distances, the situations needed to minimize are taken into consideration in addition to the situations to be maximized [19]. At the same time, in real life and in many circumstances numerical values can remain incapable by the reason of human thoughts and judgements, particularly choices contains uncertainty. TOPSIS method is developed in such a way that will be able to use fuzzy datas [20]. Fuzzy TOPSIS method enables decision-makers to assess and range the alternatives under uncertainty in respect to certain criteria, and to make the truest choice between them.

Based on this, a supplier selection in supply chain system is a group of multiple-criteria decision-making (GMCDM) problem and may be described by means of the following sets:

- (1) a set of K decision-makers called $E = \{D_1, D_2, \dots, D_K\}$;
- (2) a set of m possible suppliers (alternatives) called $A = \{A_1, A_2, \dots, A_m\}$;
- (3) a set of n criteria, $C = \{C_1, C_2, \dots, C_N\}$ with which supplier (alternative) performances are measured;
- (4) a set of performance ratings of A_i ($i = 1, 2, \dots, m$) with respect to criteria C_j ($j = 1, 2, \dots, n$), called $X = \{x_{ij}, i = 1, 2, \dots, m, j = 1, 2, \dots, n\}$.

Following this, linguistic values to be used in determining the importance weights of alternatives and in assesment of alternatives are chosen, and decision-makers evaluate the criteria and alternatives by the help of these linguistic values. The expression of these evaluations in the form of fuzzy numbers are given by Table 1 and Table 2 [2].

Table 1. Linguistic Values Used to Determine the Importance Weights of Criteria [2]

Very High (VH)	(0.8,1,1)
High (H)	(0.7,0.8,0.9)
Medium High (MH)	(0.5,0.65,0.8)
Medium (M)	(0.4,0.5,0.6)
Medium Low (ML)	(0.2,0.35,0.5)
Low (L)	(0.1,0.2,0.3)
Very Low (VL)	(0,0,0.2)



Table 2. Linguistic Values Used to Assess the Alternatives [2]

Very Good (VG)	(8,10,10)
Good (G)	(7,8,9)
Medium Good (MG)	(5,6,5,8)
Medium (M)	(4,5,6)
Medium Poor (MP)	(2,3,5,5)
Poor (P)	(1,2,3)
Very Poor (VP)	(0,0,2)

Assume that a decision group has K decision makers, and the fuzzy rating of each decision-maker $D_k (k = 1, 2, \dots, K)$ can be represented as a positive trapezoidal fuzzy number $\tilde{R}_k (k = 1, 2, \dots, K)$ with membership function $\mu_{\tilde{R}_k}(x)$. A good aggregation method should be considered the range of fuzzy rating of each decision-maker. It means that the range of aggregated fuzzy rating must include the ranges of all decision-makers' fuzzy ratings. Let the fuzzy ratings of all decisionmakers be trapezoidal fuzzy numbers $\tilde{R}_k = (a_k, b_k, c_k)$, $k = 1, 2, \dots, K$. Then the aggregated fuzzy rating can be defined as:

$$\tilde{R} = (a, b, c), k = 1, 2, \dots, ; \text{ where } a = \min_k \{a_k\}, b = \frac{1}{K} \sum_{k=1}^K b_k, c = \max_k \{c_k\} \quad (5)$$

Let the fuzzy rating and importance weight of the k th decision maker be $\tilde{x}_{ijk} = (a_{ijk}, b_{ijk}, c_{ijk})$, and $\tilde{w}_{jk} = (w_{jk1}, w_{jk2}, w_{jk3})$, $i = 1, 2, \dots, m$, $j = 1, 2, \dots, n$, respectively. Hence, the aggregated fuzzy ratings ($\tilde{x}_{ij}$) of alternatives with respect to each criterion can be calculated as;

$$\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}), \text{ where } a_{ij} = \min_k \{a_{ijk}\}, b_{ij} = \frac{1}{K} \sum_{k=1}^K b_{ijk}, c_{ij} = \max_k \{c_{ijk}\} \quad (6)$$

The aggregated fuzzy weights ($\tilde{w}_j$) of each criterion can be calculated as:

$$\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3}), \text{ where } w_{j1} = \min_k \{w_{jk1}\}, w_{j2} = \frac{1}{K} \sum_{k=1}^K w_{jk2}, w_{j3} = \max_k \{w_{jk3}\} \quad (7)$$

As stated above, a supplier-selection problem can be concisely expressed in matrix format as follows:

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \dots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix}$$

$$\tilde{W} = [\tilde{w}_1, \tilde{w}_2, \dots, \tilde{w}_n], \quad (8)$$

where $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ and $\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3})$; $i = 1, 2, \dots, m$, $j = 1, 2, \dots, n$ can be approximated by positive trapezoidal fuzzy numbers.

The normalized fuzzy-decision matrix can be represented as:

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n} \quad (9)$$

where B and C are the sets of benefit criteria and cost criteria, respectively, and;

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} \right), \quad c_j^* = \max_i c_{ij}, \quad j \in B; \quad (10)$$



$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_j}, \frac{a_j^-}{c_j}, \frac{a_j^-}{c_j} \right), \quad a_j^- = \min_i a_j, \quad j \in C; \quad (11)$$

The normalization method mentioned above is designed to preserve the property in which the elements $\tilde{r}_{ij}$, $\forall i, j$ are the standardized (normalized) trapezoidal fuzzy numbers.

Considering the different importance of each criterion, the weighted normalized fuzzy-decision matrix is constructed as:

$$\tilde{V} = [\tilde{v}_{ij}]_{m \times n}, \quad i = 1, 2, \dots, m, j = 1, 2, \dots, n \quad \text{where} \quad \tilde{v}_{ij} = \tilde{r}_{ij}(\cdot) \tilde{w}_j \quad (12)$$

According to the weighted normalized fuzzy-decision matrix, normalized positive trapezoidal fuzzy numbers can also approximate the elements $\tilde{v}_{ij}$, $\forall i, j$. Then, the fuzzy positive-ideal solution (FPIS, A^*) and fuzzy negative-ideal solution (FNIS, A^-) can be defined as:

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*), \quad (13)$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-), \quad (14)$$

$$\text{where } \tilde{v}_j^* = \max_i \{v_{ij}\} \text{ and } \tilde{v}_j^- = \min_i \{v_{ij}\}; \quad i = 1, 2, \dots, m, j = 1, 2, \dots, n \quad (15)$$

The distance of each alternative (supplier) from A^* and A^- can be currently calculated as:

$$d_i^* = \sum_{j=1}^n d_v(\tilde{v}_{ij}, \tilde{v}_j^*), \quad i = 1, 2, \dots, m, \quad (16)$$

$$d_i^- = \sum_{j=1}^n d_v(\tilde{v}_{ij}, \tilde{v}_j^-), \quad i = 1, 2, \dots, m, \quad (17)$$

where $d_v(\cdot, \cdot)$ is the distance measurement between two fuzzy numbers.

A closeness coefficient is defined to determine the ranking order of all possible suppliers once d_i^* and d_i^- of each supplier A_i ($i = 1, 2, \dots, m$) has been calculated. The closeness coefficient represents the distances to the fuzzy positive-ideal solution (A^*) and the fuzzy negative-ideal solution (A^-) simultaneously by taking the relative closeness to the fuzzy positive-ideal solution. The closeness coefficient (CC_i) of each alternative (supplier) is calculated as:

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-}, \quad i = 1, 2, \dots, m, \quad (18)$$

To sum up, an algorithm of the fuzzy decision-making method to deal with the supplier selection problem is given as follows:

Step 1: Identify the supplier selection criteria.

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

Step 3: Aggregate the weight of each criteria to get the aggregated fuzzy weight $\tilde{w}_j$ of criterion C_j , and combine the decision-makers' ratings to get the aggregated fuzzy rating $\tilde{x}_{ij}$ of supplier A_i under criterion C_j .

Step 4: Construct the fuzzy-decision matrix and the normalized fuzzy-decision matrix.

Step 5: Construct weighted normalized fuzzydecision matrix.

Step 6: Determine FPIS and FNIS.

Step 7: Calculate the distance of each supplier from FPIS and FNIS, respectively and then calculate the closeness coefficient of each supplier.



Step 8: According to the closeness coefficient, determine to select which supplier.

A Hypothetical Numerical Example

A manufacturing company wants to select a suitable material supplier to purchase the key components of new products. After preliminary screening, four candidates (A_1, A_2, A_3, A_4) remain for further evaluation. A committee of four decision makers, D_1, D_2, D_3 and D_4 has been formed to select the most suitable supplier. Four selection criteria are as follows:

- Price (C_1),
- Delivery Date (C_2),
- Quantity (C_3),
- Quality (C_4).

Step 1: Four decision-makers use the linguistic weighting values shown in Table 1 to assess the importance of the criteria. The importance weights of the criteria determined by these four decision makers are shown in Table 3.

Table 3. Importance Weights of Criteria from Four Decision Makers

Criteria	Decision Makers			
	D_1	D_2	D_3	D_4
C_1	VH	H	VH	H
C_2	H	H	H	H
C_3	H	VH	VH	H
C_4	VH	VH	H	VH

Step 2: Four decision-makers use the linguistic rating variables shown in Table 2 to evaluate the ratings of candidates with respect to each criterion. The ratings of the four candidates by the decision makers under various criteria are shown in Table 4.

Table 4. Ratings of the Four Candidates by Decision Makers Under Various Criteria

Criteria	Suppliers	Decision Makers			
		D_1	D_2	D_3	D_4
C_1	A_1	VG	VG	VG	MP
	A_2	VG	VG	MG	VG
	A_3	M	G	MP	G
	A_4	G	VG	VG	VG
C_2	A_1	MP	MG	G	VG
	A_2	VG	MG	VG	G
	A_3	MG	MP	MG	G
	A_4	G	VG	G	MP
C_3	A_1	VG	G	MG	M
	A_2	G	M	MG	VG
	A_3	VG	MG	MP	M
	A_4	VG	MP	G	M
C_4	A_1	MG	G	MG	MG
	A_2	G	VG	VG	VG
	A_3	P	G	M	MG
	A_4	VG	M	MP	G

Step 3: Then the linguistic evaluations shown in Tables 3 and 4 are converted into trapezoidal fuzzy numbers to construct the fuzzy-decision matrix and determine the fuzzy weight of each criterion, as in



Table 5 and Table 6.

Table 5. The Weights of Each Criteria

Criteria	Weights
C_1	(0.75,0.9,0.95)
C_2	(0.7,0.8,0.9)
C_3	(0.75,0.9,0.95)
C_4	(0.78,0.95,0.98)

Table 6. Fuzzy Decision Matrix

	C_1	C_2	C_3	C_4
A_1	(6.5,8.38,8.75)	(5.5,7,8)	(6,7.38,8.25)	(5.5,6.88,8.25)
A_2	(7.25,9.13,9.5)	(7.8,63,9.25)	(6,7.38,8.25)	(7.75,9.5,9.75)
A_3	(5,6.13,7.5)	(4.75,6.13,7.5)	(4.75,6.3,7.25)	(4.25,5.38,6.5)
A_4	(7.75,9.5,9.75)	(6,7.38,8.25)	(5.25,6.63,7.5)	(5.25,6.63,7.5)

Step 4: The fuzzy decision matrix is normalized with Equation (5), and normalized fuzzy decision matrix is given with Table 7.

Table 7. Normalized Fuzzy Decision Matrix

	C_1	C_2	C_3	C_4
A_1	(0.67,0.86,0.9)	(0.65,0.76,0.86)	(0.73,0.89,1)	(0.56,0.71,0.85)
A_2	(0.74,0.94,0.97)	(0.76,0.93,1)	(0.73,0.89,1)	(0.79,0.97,1)
A_3	(0.51,0.63,0.77)	(0.51,0.66,0.81)	(0.58,0.76,0.88)	(0.44,0.55,0.67)
A_4	(0.79,0.97,1)	(0.65,0.8,0.89)	(0.64,0.80,0.91)	(0.54,0.68,0.77)

Step 5: Weighted normalized fuzzy-decision matrix is constructed as in Table 8.

Table 8. Weighted Normalized Fuzzy Decision Matrix

	C_1	C_2	C_3	C_4
A_1	(0.5,0.77,0.85)	(0.45,0.68,0.82)	(0.55,0.81,0.95)	(0.42,0.64,0.8)
A_2	(0.52,0.75,0.88)	(0.53,0.75,0.9)	(0.51,0.72,0.9)	(0.56,0.78,0.9)
A_3	(0.38,0.57,0.73)	(0.39,0.6,0.77)	(0.43,0.69,0.83)	(0.33,0.5,0.63)
A_4	(0.62,0.93,98)	(0.51,0.76,0.87)	(0.50,0.76,0.89)	(0.42,0.65,0.75)

Step 6: Determine FPIS and FNIS as;

$$A^* = [(1,1,1),(1,1,1),(1,1,1),(1,1,1)],$$

$$A^- = [(0,0,0),(0,0,0),(0,0,0),(0,0,0)],$$

Step 7: Calculate the distance of each supplier from FPIS and FNIS with respect to each criterion, respectively, as Table 9 and Table 10.



Table 9. Distances Between $A_i (i=1,2,3,4)$ and A^* with respect to Each Criteria

	C_1	C_2	C_3	C_4
$d(A_1, A^*)$	0.33	0.38	0.29	0.41
$d(A_2, A^*)$	0.32	0.31	0.33	0.29
$d(A_3, A^*)$	0.46	0.44	0.39	0.53
$d(A_4, A^*)$	0.22	0.33	0.33	0.42

Table 10. Distances Between $A_i (i=1,2,3,4)$ and A^- with respect to Each Criteria

	C_1	C_2	C_3	C_4
$d(A_1, A^-)$	0.72	0.67	0.78	0.64
$d(A_2, A^-)$	0.73	0.74	0.73	0.76
$d(A_3, A^-)$	0.58	0.60	0.67	0.50
$d(A_4, A^-)$	0.86	0.73	0.73	0.62

Calculation of d_i^* , d_i^- and the closeness coefficients of each supplier are calculated in Table 11.

Table 11. Computations of d_i^* , d_i^- and CC_i

Alternatives	d_i^*	d_i^-	$d_i^* + d_i^-$	CC_i
A_1	1.41	2.82	4.23	0.67
A_2	1.26	2.96	4.22	0.7
A_3	1.82	2.36	4.18	0.56
A_4	1.3	2.94	4.24	0.69

According to these closeness coefficients, the alternatives are ranges as $A_2 > A_4 > A_1 > A_3$. In other words, for this hypothetical example implemented by fuzzy TOPSIS method, A_2 (Alternative Supplier 2) is the best candidate for this supplier selection problem.

Conclusions

The advantages of supply chain management have been presented by many researchers and firms up to now. In the light of these developments, many companies consider supply chain management as an important tool to increase the competitory advantage. In these circumstances, building the long-term relationships between buyers and suppliers is critical success factor to establish an effective supply chain system. Therefore, supplier selection problem becomes the most important issue to implement a successful supply chain system.

In general, supplier selection problems are based onto uncertain and indecisive data and fuzzy-set theory is adequate to deal with these. Due to supplier selection problems contain human judges by definition, its important to associate it with fuzzy set theory to represent the real life. In addition to these, in a decision-making process, the use of linguistic variables in decision problems is highly beneficial when performance values cannot be expressed by means of numerical values. In other words, in assessing of possible suppliers with respect to criteria and importance weights, it is appropriate to use linguistic variables instead of numerical values frequently. The fuzzy TOPSIS method can deal with the ratings of both quantitative as well as qualitative criteria and select the suitable supplier effectively. According to the closeness coefficient, we can determine not only the ranking order but also the assessment of all possible suppliers and this makes method flexible.



In this paper, a hierarchical multiple criteria decision-making model based on fuzzy sets theory with TOPSIS concept is used to deal with the supplier selection problem in the supply chain and a hypothetical example is been applied with the mentioned method. Consequently, as a result of the assesments made by 4 decision makers according to four criteria (price, delivery date, quatity and quality), the candidate suppliers are ranged as Alternative Supplier 2, Alternative Supplier 4, Alternative Supplier 1 and Alternative Supplier 3 from the best to the worse, respectively.

The proposed method provides objective information for supplier selection and evaluation in a supply chain system significantly. A statistical study can be suggested to determine the criteria and weights more rational and also to choose the decision makers more feasible. The systematic framework for supplier selection in a fuzzy environment presented in this paper can be easily extended to the analysis of other management decision problems. Besides, as a topic or suggestion for future researchs, developing a group decision support system in a fuzzy environment can be considered.



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