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A Fuzzy VIKOR Model for Supplier Selection and Evaluation: Case of EMERSUN Company

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ABSTRACT

One of the most important activities in creating an efficient supply chain is supplier selection. The supplier selection process is the process of finding appropriate suppliers who are able to provide high quality products and/or services with reasonable price in a specified time for buyer. Group multiple criteria decision making with conflicting criteria is considered as one of the applied approaches in this process. In this article, we used a fuzzy compromise solution, called fuzzy VIKOR, to select suppliers. Moreover, the fuzzy logic and trapezoidal fuzzy numbers utilized to overcome ambiguity of evaluation process. Since any organization in different industries wants to minimize risk and cost, so these two criteria are considered in structure of the proposed approach. In order to reduce risk and cost, we first used a Kraljic matrix to classify items based on above criteria and then determine the overall supply strategies for each group. Afterwards, the evaluation criteria weighted by Kraljic matrix, as a result decrease dependence of decision makers and provide more rational in decision making process. In the next phase, fuzzy VIKOR method used to rank suppliers and the supplier selection problem. Finally, the results of implementation in EMERSUN Industries presented.
Keywords: Kraljic Matrix, Selection and Evaluation of Suppliers, Fuzzy Set Theory, Fuzzy Analytic Hierarchy Process (FAHP) Method, VIKOR Method.

1. INTRODUCTION

Recently, academic environment and industry has drawn attention to supply chain management (SCM). The main objectives of SCM are reduction of supply chain risk and production costs, revenue maximization, improving customer service, inventory echelon optimization and as a result increasing competitiveness, customer satisfaction and profitability [1]. Effective purchasing operations are vital to the success of supply chain [2]. Due to the factors such as globalization, increasing value added in supply and accelerating changes in technology, purchasing operations in SCM has paid more attention. Purchasing operations include purchasing raw materials, components, and services for organization. The most important activity of purchasing operations is appropriate supplier selection, because it returns considerable savings for the organization [3]. In addition, suppliers have significant direct effect on quality, cost, time-order of new products, and required technologies to satisfy new market demands [3]. Supplier selection is a Multi-Criteria Decision Making problem (MCDM) in which the selection process is mainly involved in evaluating the ability of a number of suppliers in satisfying business requirements [4]. The rest of this article is structured as following: Section 2 presents a summary of literature review related to the supplier selection process. In Section 3 we discuss the Kraljic matrix, its dimensions and also organization's strategies related to each set of items. In Section 4 bibliography of VIKOR method and steps of this method will be explained. In Section 5 a method will be proposed to select suppliers and in Section 6 we implement the proposed approach in EMERSUN Company, producer of household appliance, for selecting supplier. Then, in Section 7 Conclusions and remarks for future research will be presented.

2. LITERATURE REVIEW

Through a supplier selection process suppliers are surveyed, evaluated and selected as a member of supply chain [5]. There are four stages in supplier selection process: (1) problem definition, (2) criteria definition, (3) initial screening of potential suppliers from large collection, and (4) selection of final suppliers [6]. Until 2000, three articles Weber, Current, and Benton [7], Degraeve, Labro, and Roodhooft [8] and De Boer, Labro, and Morlacchi [6] have reviewed the literature related to models of evaluation and selection of suppliers. Unlike other reviews, reviews of De Boer, Labro, and Morlacchi [6] do not limit their work to the final selection models. They have included all stages in the selection process from initial problem definition, criteria formulation, and determination of potential suppliers' qualification to the final selection of the best providers. Aissaoui, Haouari, and Hassini [9] presented literature review which includes all processes in purchase phase. They classified models based on number of periods and number of items (with discount and without discount).

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2-1. Selection Criteria

Supplier selection is a MCDM problem in which the selection process basically consists of evaluation of a number of suppliers based on a set of criteria to select suppliers who satisfy the organization needs [4]. Since these criteria should be aligned with organization's strategy, the evaluation criteria varies based on various factors such as product types, activities and organization strategies. Different sets of criteria have been proposed for supplier's evaluation. Dickson [10] in his empirical study identified 23 criteria that provide a framework for evaluation and supplier selection process. In that study, quality, delivery, past performance, warranties, production facilities and capacity, net price, and technical capabilities were among important criteria. Weber, Current, and Benton [7] in their review of 74 article mentioned that the criteria of price, in time delivery, quality, facilities and capacity, geographical location and technical capacity are important. Kahraman, Cebeci, and Ulukan [11] have stated that the selection criteria are placed in one of four groups: supplier criteria, product performance criteria, service performance criteria, or cost criteria.

These reveal that there is not any common knowledge of the factors which guide the decision making process. This stems from the fact that decision criteria are related with various characteristics of the buyer organization, such as its size, the sector it belongs to, etc. The proposed and considered criteria by researchers for the performance evaluation and supplier selection from 2000 to 2011 are collected and categorized in Table 1. In all these articles, analytic hierarchy process method has been used individually or in hybrid with other methods.

Table 1- Supplier selection and evaluation criteria

Selection Criteria	Authors
Product (Cost, Price, Quality, & Product innovation capabilities)	[12]; [13]; [14]; [15]; [16]; [11]; [17]; [18]; [19]; [20]; [21]; [22]; [23]; [24]; [25]; [26]; [27]; [28]; [29]; [30]; [31]; [32]; [33]; [34]; [35]; [36]; [37]; [38]; [39]; [4]; [3]; [40]; [41]; [42]
Service (After sales service, Delivery, Repair turn round time, Response to claims, Service performance, Support resource, & Warranty support)	[12]; [13]; [14]; [15]; [11]; [17]; [18]; [19]; [20]; [21]; [22]; [23]; [24]; [25]; [26]; [27]; [28]; [29]; [30]; [31]; [32]; [34]; [35]; [43]; [36]; [37]; [38]; [39]; [4]; [3]; [40]; [41]; [42]
Technology and Assets (Development, Flexibility Manufacturing facilities and capabilities, Supply capacity Technical capability, & Technological capability)	[13]; [14]; [15]; [16]; [11]; [17]; [19]; [18]; [20]; [21]; [22]; [23]; [24]; [25]; [26]; [27]; [28]; [29]; [30]; [31]; [32]; [33]; [35]; [43]; [36]; [38]; [40]; [41]; [42]
Reliability (Commitment capability, Financial position, Past performance attitude, Performance history, Political stability, Position in industry, Reputation , Responsiveness, & Terrorism)	[12]; [14]; [15]; [16]; [11]; [17]; [18]; [19]; [20]; [21]; [22]; [23]; [26]; [32]; [33]; [35]; [43]; [38]; [4]; [40]; [42]
Management and system (Discipline, Financial performance, Internal audit, IT system, Management skills, Organizational structure and control, Problem solving capability, & Training)	[12]; [15]; [16]; [11]; [17]; [20]; [21]; [23]; [26]; [28]; [33]; [34]; [43]; [38]; [4]; [3]; [42]
Relationship (Bargaining power of supplier, Communication system, Customer communication, Degree of closeness, Degree of cooperation, & Environmentally friendly features)	[15]; [16]; [11]; [20]; [22]; [28]; [33]; [34]; [43]; [35]; [3]; [41]

2-2. Supplier selection techniques

Supplier evaluation and selection problem has been widely studied and different decision making approaches for this problem have been presented. Analytical hierarchy process (AHP), analytical network process (ANP) , data envelopment analysis (DEA), genetic algorithm (GA), case based reasoning (CBR), artificial neural networks (ANN), fuzzy set theory (FST), cluster analysis (CA), expert system ,mathematical programming (MP), multi objective programming (MOP) , goal programming (GP), technique for order preference by similarity to ideal solution (TOPSIS) and the combination of approaches are some techniques presented to solve this problem. Supplier selection and evaluation techniques have been run over briefly and some examples have been collected in relation to each presented technique in Table 2.

After reviewing existing literature, in this paper, first Kraljic matrix approach is used to identify strategic items. Evaluation criteria are weighted using Kraljic matrix and the alternatives under evaluation are weighted using fuzzy set theory. In order to find suitable suppliers for strategic item fuzzy VIKOR method is utilized. Integrating these two approaches persuades the organization to allocate limited resources based on a selection that minimizes supply risk and maximizes turnover. In this model, risk and cost criteria will guide decision-making process. Different companies have various special requirements in connection with evaluation of supplier, because they are managed in different industries, markets, and parts and with various customer requirements. Nevertheless, minimizing risk and cost are prior objectives of every organization and industry.

Table 2- Supplier selection and evaluation techniques

Techniques	Authors	Techniques	Authors
AHP	[22]; [24]	DEA + ANN	[44]
ANP	[45]; [46]	FST+ANP	[47]
DEA	[48]; [5]	FST + GA	[49];[50]
LP	[51];[52]	FST+LP	[53]
Integer LP	[54]	FST + GP	[55]
Integer Non-LP	[56]	FTS + MOP	[57];[58]
GP	[59]	FST + TOPSIS	[60]
MOP	[61];[62]	ANP + TOPSIS	[63];[64]
FST	[65];[66]	FST + QFD	[67];[68]
CBR	[69];[70]	FST+VIKOR	[71];[72]
Genetic algorithm	[73]	GA + MOP	[74]
Grey approach	[75]	MP + TCO	[76]
Artificial neural network	[77];[78]	MIP + CBR	[79]
AHP+ Grey approach	[21]	MIP + DM	[80]
AHP + GP	[20];[29]	CBR+DM	[81]
AHP + FST	[22];[35];[42]	AHP+ DEA+ TCO	[25]
AHP + DEA	[26]	AHP+ DEA+ANN	[28]
AHP + MOP	[27]	DEA+DM+ANN	[82]
AHP + MP	[83]	DEA+ANP+ANN	[84]
AHP +Non-LIP	[34]	ANP+MOP+MIP	[85]
AHP +Mixed integer Non-lp	[31]	FST+AHP+GP	[86]
AHP+QFD	[38]	FTS+AHP+CA	[87]
Non-lp	[88]	FST+MOLP+ANP	[89]
Data mining(DM) +Set theory	[90]	FST+Non-LP+ANP	[91]
ANP + GP	[92]	FST+DEA+TOPSIS	[93]
ANP + MIP	[94]	FST+AHP+TOPSIS	[36];[3];[41]
DEA + TCO	[95]	FST+ANP+TOPSIS	[96]
DEA + MOP	[97]	FST+ GP+TOPSIS	[98]

3. Supply risk and strategic items identification

Supply risks are various risks related to inbound supply that effect purchasing organizations [99]. Supply risk is defined as potential occurrence of a negative incident associated with suppliers in the supply base that prevents the contractor's ability to meet its customers' demands [100]. One of the pioneering studies in the field of portfolio models was performed by Kraljic [101]. He presented a strategic approach in order to identify different strategies for purchasing and supply management. Kraljic's model classifies a firm purchased items based on (1) profit impact, and (2) supply risk (see Fig. 1.). This model proposed a framework in which the organization must first classify the whole of purchased and required items in terms of impact on profitability and supply risk, and then determine its sourcing strategies based on these items.

Group 3: leverage items	**Group 4: strategic items**
materials management ↓ using buying position	supply management ↓ providing competitive advantage
Group 1: normal items	**Group 2: bottleneck items**
purchasing management ↓ low price	resource management ↓ supply guarantee

Fig. 1 Kraljic matrix for items classifying

First group of items: these items have low value and rather little risk. The main focus of this group is on automation and simplification of the buying process and using standard products. Given that this group of goods has a low supply risk and low cost, we decided that this group of items deleted from our research.

Second group of items: This group has risk in supply, but little benefit. Therefore purchase department create some strategies for supply guarantee.

Third group of items: This group provides a high profit for the organization and also a large number of suppliers in relation to supply these items are available. For this group of items several sources should be used to maintain in competitive conditions.

Fourth group of items: Theses items have the highest potential for providing competitive advantage. So the majority of buyer's efforts and its resources should be spent on the goods in this category. Considering high sensitivity and high importance of this group of goods in an organization, high-level managers, themselves make decision about suppliers.

4. VIKOR

VIKOR method is an effective decision tool for multi-criteria optimization of complex systems. This method focuses on ranking and selecting a set of alternatives, and help decision makers to make the final decision [102]. This method introduces multi-criteria ranking list based on "closeness" to “ideal" solution [103]. Here a compromise solution is a feasible solution that is closest to the ideal, and compromise means an agreement established by mutual concessions [104].

In VIKOR the multi-criteria measure for compromise ranking is developed from the Lp-metric that is used as an aggregating function in compromise programming. Different alternatives are indicated with A_1, A_2, …, A_J. Rating of A_j with regard to aspect *i* displayed with f_{ij}. For example, f_{ij} is the value of *i*th criterion function for alternative A_j; n is the number of criteria. Development of the VIKOR method is started with the following form of LP-metric:

$$L_{P,j} = \left\{ \sum_{j=1}^{n} [(f_j^* - f_{ij})/(f_j^* - f_j^-)]^P \right\}^{1/P}, 1 \le P \le \infty; j = 1,2,\ldots,J. \tag{1}$$

In the VIKOR method $L_{1,j}$(as S_j) and $L_{\infty,j}$ (as R_j) are used to formulate ranking measure. The solution obtained by min S_j is with a maximum group utility (‘‘majority” rule), and the solution obtained by min R_j is with a minimum individual regret of the ‘‘opponent”.

5. Fundamentals of fuzzy set theory

The fuzzy set theory was proposed by Zadeh [105] to address the vagueness in the preferences and human judgment. Fuzzy sets and fuzzy logic are powerful mathematical tools for modeling and handling ambiguity preferences and uncertainty in supplier selection process. In a universe set of discourse X, a fuzzy subset Ã of X is defined with a membership function $\mu_{\tilde{A}}(X)$ that maps each element x in X to a real number in the interval [0,1]. The function value of $\mu_{\tilde{A}}(X)$ indicates the degree of membership of x in Ã set. A trapezoidal fuzzy number Ã can be defined as (a_1, a_2, a_3, a_4), as shown in Fig. 2. In a trapezoidal fuzzy number Ã = (a_1, a_2, a_3, a_4), if $a_2=a_3$, then Ã names a triangular fuzzy number. Also a crisp value r can be expressed as (r,r,r,r).

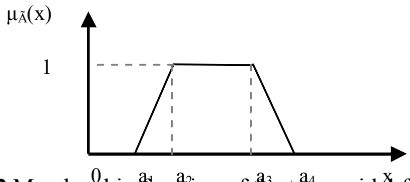


Fig. 2 Membership function of the trapezoidal fuzzy number Ã

Given two positive trapezoidal fuzzy numbers Ã= (a_1, a_2, a_3, a_4), $\tilde{B} = (b_1, b_2, b_3, b_4)$ and a positive real number r, some main operations of fuzzy numbers Ã and $\tilde{B}$ employed in our study can be expressed as follows:

$$\tilde{A} \oplus \tilde{B} = [a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4] \tag{2}$$

$$\tilde{A} \Theta \tilde{B} = [a_1 - b_1, a_2 - b_2, a_3 - b_3, a_4 - b_4] \tag{3}$$

$$\tilde{A} \otimes \tilde{B} = [a_1 \times b_1, a_2 \times b_2, a_3 \times b_3, a_4 \times b_4] \tag{4}$$

$$\tilde{A}^{-1} = [1/a_4, 1/a_3, 1/a_2, 1/a_1] \tag{5}$$

The operations of $\vee$ for maximum and $\wedge$ for minimum are described as follows:

$$\tilde{A}(\vee)\tilde{B} = [a_1 \vee b_1, a_2 \vee b_2, a_3 \vee b_3, a_4 \vee b_4] \tag{6}$$

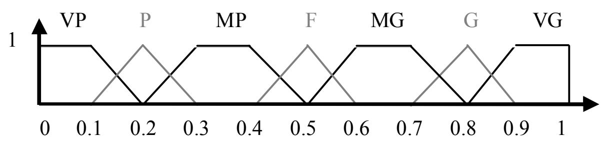
$$\tilde{A}(\wedge)\tilde{B} = [a_1 \wedge b_1, a_2 \wedge b_2, a_3 \wedge b_3, a_4 \wedge b_4] \tag{7}$$

In addition, this research uses linguistic variables to determine the importance of criteria of evaluation and ranking the alternatives, as shown in Tables 3 and 4.

Table 3- A linguistic scale for importance weighting of each criterion

Membership functions for linguistic variables comparison criteria	Linguistic variables for important criteria	Trapezoidal fuzzy numbers
	Very Low (VL) Low (L) Medium Low (ML) Medium(M) Medium High (MH) High (H) Very High (VH)	(0.0,0.0,0.15,0.15) (0.15,0.15,0.3,0.3) (0.3,0.3,0.45,0.45) (0.45,0.45,0.55,0.55) (0.55,0.55,0.7,0.7) (0.7,0.7,0.85,0.85) (0.85,0.85,1.0,0.1)

Table 4 - A linguistic scale for rating alternatives

Membership functions of linguistic variables	Linguistic variables for rating alternatives	Trapezoidal fuzzy numbers
	Very Poor (VP)	(0.0,0.0,0.1,0.2)
	Poor (P)	(0.1,0.2,0.2,0.3)
	Medium Poor (MP)	(0.2,0.3,0.4,0.5)
	Medium(M)	(0.4,0.5,0.5,0.6)
	Medium Good (MG)	(0.5,0.6,0.7,0.8)
	Good (G)	(0.7,0.8,0.8,0.9)
	Very Good (VG)	(0.8,0.9,1.0,1.0)

To obtain ranking alternatives, fuzzy numbers must be converted into crisp real numbers [2] . This research uses the Center of Area (COA) method because of its simplicity of application. Crisp value of the fuzzy number $\tilde{A} = (a_1, a_2, a_3, a_4)$ based on center of area method can be explained with the following equation:

$$defuzz(\tilde{A}) = \frac{\int x.\mu(x)dx}{\int \mu(x)dx}$$

$$= \frac{\int_{a_1}^{a_2} (\frac{x-a_1}{a_2-a_1}).xdx + \int_{a_2}^{a_3} xdx + \int_{a_3}^{a_4} (\frac{a_4-x}{a_4-a_3}).xdx}{\int_{a_1}^{a_2} (\frac{x-a_1}{a_2-a_1})dx + \int_{a_2}^{a_3} dx + \int_{a_3}^{a_4} (\frac{a_4-x}{a_4-a_3})dx}$$

$$= \frac{-a_1a_2 + a_3a_4 + \frac{1}{3}(a_4-a_3)^2 - \frac{1}{3}(a_2-a_1)^2}{-a_1 - a_2 + a_3 + a_4} \qquad (8)$$

6. Fuzzy analytic hierarchy process

Analytic hierarchy process (AHP) is one of the multi-criteria decision-making (MCDM) methods which has been widely used and first was proposed by Saaty [106]. Although comprehension of the method is simple for researchers and decision makers, using this method we would not be able to effectively handle the uncertainties of data and vagueness of human judgments in the decision making process. To overcome this shortcoming Buckley [107] combined fuzzy set with analytic hierarchy process, and called its fuzzy analytic hierarchy process. The procedure of this method for determining the evaluation weights are explained as following [108]:

Step 1: Constructing fuzzy pair wise comparison matrices. Through questionnaires, each expert is asked to assign a linguistic term shown in Table 5 to the pair wise comparisons among all the criteria existing in a same level in the hierarchical structure. The result of the comparisons is constructed as fuzzy pair wise comparison matrices ($\tilde{A}$) as shown in equation (9).

Table 5- Membership functions of the fuzzy numbers

Fuzzy numbers	Linguistic scales	TFN($\tilde{a}_{ij}$)	Reciprocal of a TFN($\tilde{a}_{ij}$)
$\tilde{9}$	Absolutely important	(8,9,9,9)	(1/9,1/9,1/9,1/8)
$\tilde{7}$	Very strongly important	(6,7,7,8)	(1/8,1/7,1/7,1/6)
$\tilde{5}$	Essentially important	(4,5,5,6)	(1/6,1/5,1/5,1/4)
$\tilde{3}$	Weakly important	(2,3,3,4)	(1/4,1/3,1/3,1/2)
$\tilde{1}$	Equally important	(1,1,1,2)	(1/2,1,1,1)
$\tilde{2},\tilde{4},\tilde{6},\tilde{8}$	Intermediate value between two adjacent judgments		

Step 2: Examine the consistency of the fuzzy pair wise comparison matrices. According to the research of Buckley (1985), if A= [a_{ij}] is a positive reciprocal matrix then $\tilde{A}$= [$\tilde{a}_{ij}$] is a fuzzy positive reciprocal matrix. Therefore, if the result of the comparisons of A= [a_{ij}] is consistent, then it can imply that the result of the comparisons of $\tilde{A}$= [$\tilde{a}_{ij}$] is also consistent. Thus, this research employs this method to validate the questionnaire.

$$\tilde{A}=\begin{bmatrix}1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n}\\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1\end{bmatrix}=\begin{bmatrix}1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n}\\ 1/\tilde{a}_{12} & 1 & \cdots & \tilde{a}_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ 1/\tilde{a}_{n1} & 1/\tilde{a}_{2n} & \cdots & 1\end{bmatrix} \tag{9}$$

Step 3: Computing the fuzzy geometric mean of each criterion. The geometric technique is used to determine the geometric mean $(\tilde{r}_i)$ of the fuzzy comparison values of criterion *i* to each criterion, as shown in equation (10), where $\tilde{a}_{in}$ is a fuzzy value of the pair-wise comparison of criterion *i* to criterion *n*.

$$\tilde{r}_i=\left[\tilde{a}_{i1}\otimes\cdots\otimes\tilde{a}_{in}\right]^{1/n} \tag{10}$$

Step 4: Calculate the fuzzy weights by normalization process. By using equation (11), the fuzzy weight of the *i*th criterion $(\tilde{w}_i)$, can be resulted, where $\tilde{w}_i$ is denoted as $\tilde{w}=(l_{wi},M_{wi},M_{wi},U_{wi})$ by a TFN and L_{wi}, M_{wi}, and U_{wi} represent the lower, middle and upper values of the fuzzy weight of the *i*th criterion.

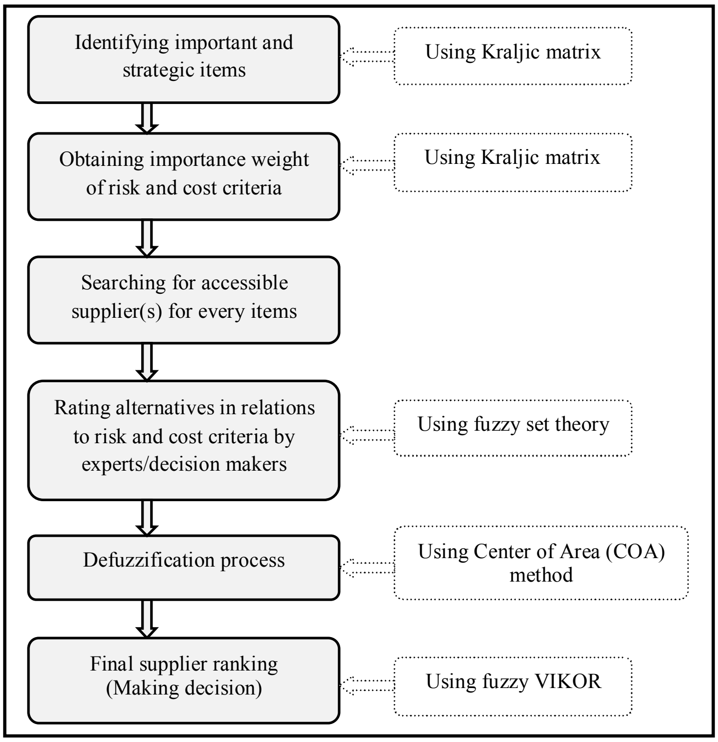
$$\tilde{w}_i=\tilde{r}_i\otimes\left(\tilde{r}_1\oplus\tilde{r}_2\oplus\cdots\oplus\tilde{r}_n\right)^{-1} \tag{11}$$

7. Method proposed for supplier selection

Analytic structure of the proposed method for selecting suppliers is shown in Fig. 3. In this Figure stages of the method are fully shown with applied tools in every stage.

In order to solve the supplier selection problem in a fuzzy environment, in this section a systematic approach will be presented to develop the VIKOR method. Since in this approach we used Kraljic matrix and supply risk and costs as its two dimensions to weight the criteria, hence forward we use the two criteria for supplier evaluation. In this approach, we use linguistic variable membership function for risk and cost criteria importance weights. Since linguistic evaluations are only decision makers' approximate evaluations of subjective judgments, we can consider linear trapezoidal membership function as an appropriate method to overcome the ambiguity of this evaluation.

Fig. 3 Supplier selection and evaluation framework in this study



In fact, supplier selection in a supply chain system is a group MCDM which can be described through the following sets:

1. E = {D_1, D_2, ..., D_K}: set of K decision makers
2. M = {M_1, M_2, ..., M_j}: organization required items are classified by using Kraljic matrix based on their effects on supply risk and profitability for organization, and then important and strategic items are identified to reduce supply risks and organization costs. These items are collected in set M.
3. A = {A_1 , A_2 , …, A_m}: set of m possible supplier for each existing item in set M is called
4. X = { X_{ij}, i = 1, 2,…, n , j = 1,2,…,J}: set of performance ratings for A_j(j = 1, 2, …, J), in respect of criteria C_i(i = 1,2,…, n)

Main steps of algorithm:
Step 1: Identifying sub criteria of appropriate supply risk by experts in organization.
Step 2: Classifying supply risk sub criteria. Generally, we could classify chosen risks based on the measurement method on two qualitative and quantitative categories. There are also two other positive and negative categories; if their ascendant trend increases or the risk it is positive and if it decreases the risk it is negative. Totally, available criteria can be divided into four categories:

Category A - Quantitative criteria that their increase increases risk, such as average delivery time to the factory warehouse.
Category B - Quantitative criteria that their increase decreases risk, such as number of available suppliers.
Category C - Qualitative criteria that their increase increases risk, such as part technology level.
Category D - Qualitative criteria that their increase decreases risk, Such as financial status of supplier.

Step 3: Calculating weight of each sub criteria using fuzzy analytical hierarchy process method.
Step 4: Calculating supply risk coefficient for each item, considering supply risk sub criteria for each item among the identified strategic items.
If risk sub criterion is one of A and C category, the supply risk coefficient of this item related to this criterion is achieved in the following way:
Assume W_i is sub criterion weight of ith risk, C_{ji} is numerical values of item j from sub criterion of risk i, and RF_{ji} is the risk coefficient of item j related to risk sub criterion i, then we have:

$$RF_{ji} = W_{ji} \times \frac{C_{ji}}{\sum_j C_{ji}} \qquad (12)$$

If the corresponding to risk sub criterion is in categories B and D, the supply risk coefficient of relevant item corresponding to that sub criterion is achieved as following:
If we assume that $W_{i'}$ is the i' th sub criterion weight of risk, $C_{ji'}$ is the numerical value of item j from the i' th sub criterion risk and also $RF_{ji'}$ is the risk coefficient of item j corresponding to i' th sub criterion risk, then we have:

$$RF_{ji'} = W_{i'} \times \frac{1/C_{ji'}}{\sum_j 1/C_{ji'}} \qquad (13)$$

Supply risk coefficient for each item j (RF_j) is obtained from the following equation. Based on this equation, for items that have the maximum supply risk, relevant supply risk coefficient is equal to 1 and for the rest items coefficient will be between 0 and 1.

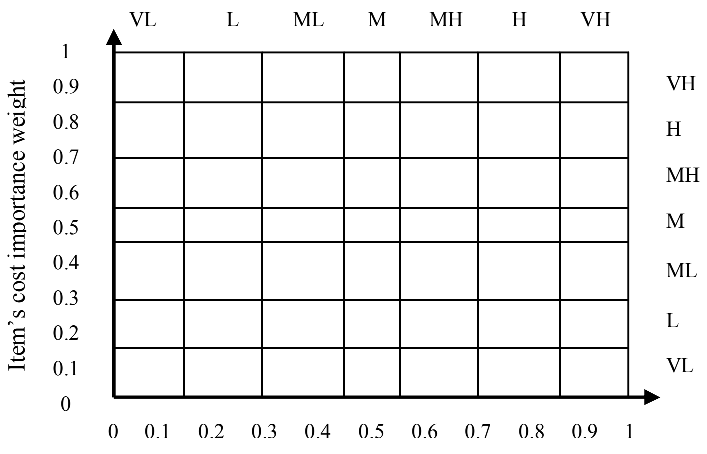
$$RF_j = \frac{\sum_i RF_{ji} + \sum_{i'} RF_{ji'}}{\max_j \left\{ \sum_i RF_{ji} + \sum_{i'} RF_{ji'} \right\}} \qquad (14)$$

Step 5: Calculating the cost ratio of each item (S_j) with regard to P_j, as the price of each item, by means of the relationship (15).

$$S_j = \frac{P_j}{Max_j \{P_j\}} \qquad (15)$$

Step 6: Determining the status of each item in Kraljic matrix (realistic situation) in Table 6, using the values obtained from steps 4 and 5.

Table 6- The importance weight of risk and cost criteria for each item



Step 7: Determining pessimistic position: realistic value minus the percentage of gained numbers for risk coefficient and cost ratio so that numerical values are not negative and also optimistic position: realistic value plus the percentage of the same numerical value in pessimistic position. The overall fuzzy weight $(\widetilde{w}_i)$ for each criterion can be calculated in the following way:

$$\widetilde{W}_i = (w_{i1}, w_{i2}, w_{i3}, w_{i4}) \tag{16}$$

where:

$$w_{i1} = \min_{K'}\{w_{ik'1}\}, w_{i2} = \frac{1}{3}\sum_{k'=1}^{3} w_{ik'2}, w_{i3} = \frac{1}{3}\sum_{k'=1}^{3} w_{ik'3}, w_{i4} = \max_{K'}\{w_{ik'4}\}.$$

In these relations, k′ represents the three realistic, optimistic and pessimistic positions.

Step 8: Determining evaluation alternatives of problem. For these alternatives, in order to evaluate all the alternatives regarding to each criterion a fuzzy judgment matrix will be constituted, in which experts will appropriate a proper fuzzy number to alternatives, based on linguistic variable in Table 4 and the result will be assembled in a pair-wise comparison matrix.

Step 9: Collecting decision makers' opinion to obtain the overall fuzzy rating for alternatives and creating a fuzzy decision matrix. Due to differences among experts' judgment in rating the alternatives, to achieve an applied and rational evaluation, the overall value should be assignment to combine different opinions of experts. To achieve a combined value we do as following:

Let $\widetilde{x}_{ijk} = (x_{ijk1}, x_{ijk2}, x_{ijk3}, x_{ijk4})$ the fuzzy rating and importance weight of K decision makers be; j = 1, 2, …,J and i = 1, 2, …, n. Thus, the overall fuzzy ratings ($\widetilde{x}_{ij}$) of alternatives could be calculated according to each criterion in this way:

$$\widetilde{x}_{ij} = (x_{ij1}, x_{ij2}, x_{ij3}, x_{ij4}), \tag{17}$$

Where:

$$x_{ij1} = \min_K\{x_{ijk1}\}, x_{ij2} = \frac{1}{K}\sum_{k=1}^{K} x_{ijk2}, x_{ij3} = \sum_{k=1}^{K} x_{ijk3}, x_{ij4} = \max_K\{x_{ijk4}\}.$$

A supplier selection can be briefly stated in a matrix like the follows:

$$\widetilde{D} = \begin{bmatrix} \widetilde{x}_{11} & \widetilde{x}_{12} & \cdots & \widetilde{x}_{1n} \\ \widetilde{x}_{21} & \widetilde{x}_{22} & \cdots & \widetilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \widetilde{x}_{m1} & \widetilde{x}_{m2} & \cdots & \widetilde{x}_{mn} \end{bmatrix}, \widetilde{W} = [\widetilde{w}_1 \widetilde{w}_2 \cdots \widetilde{w}_n]; \tag{18}$$

$\widetilde{x}_{ij}$ is rating of alternative A_j considering C_i , $\widetilde{x}_{ij} = (x_{ij1}, x_{ij2}, x_{ij3}, x_{ij4})$ and $\widetilde{w}_i$ importance weight of ith criterion; i=1,2,…,n , j=1,2,…,J are linguistic variables that could be estimated by positive trapezoidal fuzzy numbers.

Step 10: Defuzzification process for fuzzy decision matrix and fuzzy weight for each criterion and converting them to crisp values (using the equation (8)).

Step 11: Determining values of the best f^*_i and the worst f^-_i criteria ratings, $i = 1,2, ..., n$.

$$f_i^* = \max_j x_{ij}; \tag{19}$$

$$f_i^- = \min_j x_{ij}. \tag{20}$$

Step 12: Values S_j and R_j are calculated using following relationships:

$$S_j = \sum_{i=1}^{n} w_i (f_i^* - f_{ij})/(f_i^* - f_i^-) \tag{21}$$

$$R_j = \max_i w_i (f_i^* - f_{ij})/(f_i^* - f_i^-) \tag{22}$$

In which w_i are criteria's weights that express their relative importance. S_j and R_j are in the [0,1] that 0 and 1 are best and worst states respectively.

Step 13: Q_j values are calculated using following relationships:

$$Q_j = v(S_j - S^*)/(S^- - S^*) + (1-v)(R_j - R^*)/(R^- - R^*) \tag{23}$$

In which $S^* = \min_j S_j$، $S^- = \max_j S_j$، $R^* = \min_j R_j$ and $R^- = \max_j R_j$ and v belongs to [0,1]. In this study, the value of v is equal to 0.5.

Step 14: Alternative ranking, categorized with values R, S and Q in descending order.

Step 15: Proposing a compromising solution in which the alternative ($A^{(1)}$) has the best rank regarding the index Q (minimum), if the following two conditions are satisfied:

C_1 . The acceptable advantage:

$Q(A^{(2)}) - Q(A^{(1)}) \geq DQ$

That alternative $A^{(2)}$ is ranked second in the list Q; $DQ = 1 / (J-1)$ where J is the number of alternatives.

C_2 . Acceptable stability in decision making:

Also $A^{(1)}$ should be the best order obtained through S or/and R. This compromise solution is stable within a decision making process, which could be: "voting by rule of majority" (when $v > 0.5$ is needed), or ''by consensus" $v \approx 0.5$, or ''with veto" ($v < 0.5$). Here, v is the weight of decision making strategy ''the majority of criteria" (or ''the maximum group utility").

If one of these conditions does not satisfy, a set of compromise solutions offered, including:

- Alternatives $A^{(1)}$ and $A^{(2)}$, If only condition C_2 is not satisfied, or
- Alternatives $A^{(1)}$, $A^{(2)}$, … , $A^{(M)}$,If the condition C_1 does not satisfy; for the maximum M, $A^{(M)}$ is determined through the relation $Q(A^{(M)}) - Q(A^{(1)}) \prec DQ$.

Obtained compromise solution could be accepted through decision makers, because it provides the maximum "group benefit" (with the index S i.e. relationship (21) which indicates "concordance") and a minimum of the individual regret (with the index R i.e. relationship (22) that indicate "disconcordance") of the "opponent". Compromise solutions may be based on negotiations, which include priority of decision makers' thorough criteria's weights [102].

8. Case Study

EMERSUN Company is one of the considerable suppliers of home appliance in Iran and has been cooperating with more than 300 suppliers to provide its raw materials. The model for a supplier selection process in home appliance producer factory, EMERSUN, was proposed according to these following steps:

A committee of three decision makers D_1, D_2, D_3 for selecting suitable suppliers (A_1, A_2, A_3, A_4) was assembled.

Step 1 and 2: Fourteen cases as the sub criteria of supply risk in the organization were identified and categorized.

These include: The number of available suppliers (Category B), The number of potential suppliers (Category D), Political risk (Category C), Geographical availability (Category D), Lead time (Category A), Financial status (Category D), Quality (Category D), Flexibility in changing demand (Category D), Flexibility in scheduling production and delivery (Category D), Part technology level (Category C), Possible storage (Category D), Flexibility in Short term situation (Category D), Competitive demand (Category C), and Patent (Category A).

Step 3: Calculating weight of each sub criterion using fuzzy analytical hierarchy process method.

In this step, sub criteria of supply risk are calculated by using fuzzy analytical hierarchy process method. The hierarchy of weights to the criteria has been shown in Fig. 4.

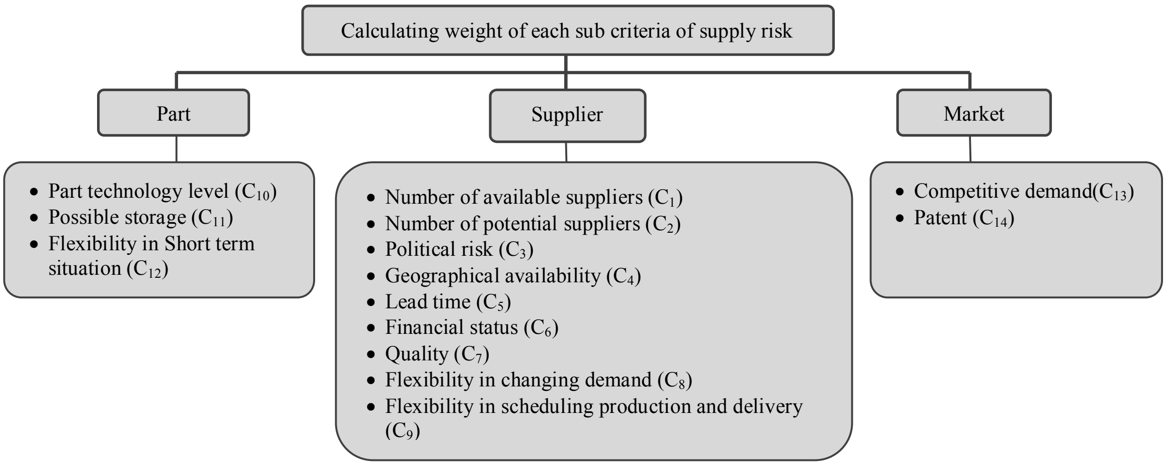


Fig. 4 Sub criterion of supply risk hierarchy structure

Constructing fuzzy pair-wise comparison matrices. Through questionnaires, each expert is asked to assign a linguistic term shown in Table 5 to the pair-wise comparisons among all the criteria existing in a same level in the hierarchical structure. Then, a comprehensive pair-wise comparison matrix by integrating opinions of decision makers (The result of the comparisons is in Tables 7, 8 and 9.).

Table 7- A comprehensive fuzzy pair-wise comparison matrix regarding to supplier

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	(1,1,1,1)	(2,3.33,3.33,5)	(2,3.67,3.67,5)	(8,9,9,9)	(6,7,7,8)	(7,8.33,8.33,9)	(1,2,2,3)	(3,4.33,4.33,6)	(1,1,1,2)
C_2	(0.2,0.31,0.31,0.5)	(1,1,1,1)	(1,2,2,3)	(6,7,7,8)	(4,5,5,6)	(6,7,7,8)	(0.25,0.39,0.39,1)	(2,3,3,4)	(0.25,0.33,0.33,0.5)
C_3	(0.2,0.28,0.28,0.5)	(0.33,0.5,0.5,1)	(1,1,1,1)	(5,6,6,7)	(3,4.67,4.67,6)	(5,6,6,7)	(0.25,0.33,0.33,0.5)	(1,2,2,3)	(0.2,0.28,0.28,0.5)
C_4	(0.11,0.11,0.11,0.125)	(0.125,0.14,0.14,0.17)	(0.14,0.17,0.17,0.2)	(1,1,1,1)	(0.25,0.33,0.33,0.5)	(0.33,0.5,0.5,1)	(0.11,0.12,0.12,0.14)	(0.14,0.18,0.18,0.25)	(0.11,0.12,0.12,0.14)
C_5	(0.125,0.14,0.14,0.17)	(0.17,0.2,0.2,0.25)	(0.17,0.22,0.22,0.33)	(2,3,3,4)	(1,1,1,1)	(2,3,3,4)	(0.125,0.15,0.15,0.2)	(0.2,0.25,0.25,0.33)	(0.125,0.14,0.14,0.17)
C_6	(0.11,0.12,0.12,0.14)	(0.125,0.14,0.14,0.17)	(0.14,0.17,0.17,0.2)	(1,2,2,3)	(0.25,0.33,0.33,0.5)	(1,1,1,1)	(0.11,0.13,0.13,0.17)	(0.17,0.2,0.2,0.25)	(0.11,0.13,0.13,0.17)
C_7	(0.33,0.5,0.5,1)	(1,2.67,2.67,4)	(2,3,3,4)	(7,8.33,8.33,9)	(5,6.67,6.67,8)	(6,7.67,7.67,9)	(1,1,1,1)	(3,4,4,5)	(0.33,0.5,0.5,1)
C_8	(0.17,0.23,0.23,0.33)	(0.25,0.33,0.33,0.5)	(0.33,0.5,0.5,1)	(4,5.67,5.67,7)	(3,4,4,5)	(4,5,5,6)	(0.2,0.25,0.25,0.33)	(1,1,1,1)	(0.17,0.2,0.2,0.25)
C_9	(0.5,1,1,1)	(2,3,3,4)	(2,3.67,3.67,5)	(7,8.67,8.67,9)	(6,7,7,8)	(6,8,8,9)	(1,2,2,3)	(4,5,5,6)	(1,1,1,1)

Table 8- A comprehensive fuzzy pair-wise comparison matrix regarding to part

	C_{10}	C_{11}	C_{12}
C_{10}	(1,1,1,1)	(0.25,0.44,0.44,1)	(1,2.67,2.67,4)
C_{11}	(1,2.33,2.33,4)	(1,1,1,1)	(3,4.67,4.67,6)
C_{12}	(0.25,0.39,0.39,1)	(0.17,0.22,0.22,0.33)	(1,1,1,1)

Table 9- A comprehensive fuzzy pair-wise comparison matrix regarding to market

	C_{13}	C_{14}
C_{13}	(1,1,1,1)	(0.14,0.18,0.18,0.25)
C_{14}	(4,5.67,5.67,7)	(1,1,1,1)

Corresponding with steps 3 and 4 fuzzy analytic hierarchy process (Section 6), we obtain geometric mean and fuzzy weights for each sub criteria (The results are in Tables 10.).

Steps 4 and 5: Calculating the supply risk coefficient and share of cost of each set of available items in set M. Considering the calculations, 7 supplied items of the organization are categorized in group 2 and another 7 are categorized in group 3. Item 26 is included in group 2.

Supply risk coefficient of item 26 = 0.7360 and share of cost of item 26 =0.0714

Step 6 and 7: Specified the position of item in Kraljic matrix (Table 6) and the relevant linguistic variable is assigned for weighting each criterion using Table 3. For each item three positions are determined, position that determined according to value numbers, optimistic position and pessimistic position that the results shown in Table 11.

Share of cost = 0.0714

Optimistic position: 0.0714 +0.02 = 0.0914 and pessimistic positions: 0.0714 -0.02 = 0.0514
Risk coefficient = 0.7360
Optimistic position: 0.7360 +0.02 = 0.756 and pessimistic position: 0.7360- 0.02 = 0.716

Table 10- Fuzzy weight of supply risk criteria for items

Risk sub criteria	Fuzzy weight of each sub criteria
Number of available suppliers	(0.14141,0.24521,0.24521,0.43279)
Number of potential suppliers	(0.06482,0.11440,0.11440,0.21667)
Political risk	(0.04819,0.08569,0.08569,0.16694)
Geographical availability	(0.01056,0.01790,0.01790,0.02773)
Lead time	(0.01841,0.02957,0.02957,0.05081)
Financial status	(0.01214,0.02176,0.02176,0.03291)
Quality	(0.09735,0.17980,0.17980,0.33074)
Flexibility in changing demand	(0.13093,0.24410,0.24410,0.39090)
Flexibility in scheduling production and delivery	(0.04404,0.06156,0.06156,0.11150)
Part technology level	(0.12196,0.28501,0.28501,0.65625)
Possible storage	(0.27922,0.59693,0.59693,1.19249)
Flexibility in Short term situation	(0.06712,0.11807,0.11807,0.28664)
Competitive demand	(0.12015,0.15047,0.15047,0.21026)
Patent	(0.63578,0.84953,0.84953,1.11261)

Table 11- Importance weight of criteria based on the three positions of item 26 in kraljic matrix

Criteria	Item position		
	Pessimistic	Realistic	Optimistic
Risk	H	H	H
Cost	VL	VL	VL

Also, the calculation of criteria weights using the relationship (16):
Risk criteria weight = (0.70, 0.70, 0.85, 0.85) and cost criteria weight = (0.0, 0.0, 0.15, 0.15)
Steps 8 and 9: There are 4 suppliers for this item, the three decision makers announced their comments using linguistic variables in Table 4 and results are shown in Table 12.

Table 12- Rating four suppliers by three decision makers with regard to both risk and cost criteria.

Decision maker	D_1				D_2				D_3			
Suppliers / Criteria	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4
Risk	F	MG	F	MG	F	MG	F	MG	MP	F	F	MG
Cost	G	MG	VG	G	MG	MG	VG	MG	G	MG	G	MG

We convert evaluations of Table 12 to the trapezoidal fuzzy numbers (results are shown in Table 13).
Table 13- Aggregated fuzzy rating of suppliers.

Fuzzy rating / Criteria	S_1	S_2	S_3	S_4
Risk	(0.20,0.43,0.47,0.60)	(0.40,0.57,0.63,0.80)	(0.40,0.50,0.50,0.60)	(0.50,0.60,0.70,0.80)
Cost	(0.50,0.73,0.77,0.90)	(0.50,0.60,0.70,0.80)	(0.70,0.87,0.93,0.1)	(0.50,0.73,0.77,0.90)

Step 10: Defuzzification process of decision matrix fuzzy weights of each criterion (Table 14).
Table 14- Crisp values of decision matrix and criteria weights.

Criteria	S_1	S_2	S_3	S_4	Weight
Risk	0.4182	0.5364	0.5000	0.6500	0.7750
Cost	0.7182	0.6500	0.8694	0.7000	0.0750

Step 11: Determining of the best and worst values for each criterion (Table 15).
Table 15- Determining of the best and worst values.

Criteria	Risk	Cost
f^*_j	0.6500	0.8694
f^-_j	0.4182	0.6500

Step 12 and 13: calculation of S_j, R_j and Q_j values for all suppliers (Table 16).
Table 16- Obtaining values of S, R and Q for all suppliers.

Suppliers	S_1	S_2	S_3	S_4
S	0.8267	0.4549	0.5015	0.0579
R	0.7750	0.3799	0.5015	0.0579
Q	1.0000	0.4827	0.5978	0

Step 14: Ranking of suppliers, using the values S, R and Q respectively in descending order and obtaining three ranking list (Table 17).

Table 17- Ranking of suppliers using the values S, R and Q in descending order

Supplier ranking / Ranking lists	1	2	3	4
S	S_4	S_2	S_3	S_1
R	S_4	S_2	S_3	S_1
Q	S_4	S_2	S_3	S_1

Step 15: Selecting the best choice. Best alternative is the lowest value of Q (in this problem, it is $DQ=1/(4-1)\approx 0.33$). As we see in the Table 17 and considering conditions C_1 and C_2 (step 15) ranking of the suppliers will be: $S_4>S_2=S_3>S_1$.
For each group of items of groups 2 and 3, we run this process and eventually results are shown in Table 18.

Table 18- Results from items of groups 2 and 3

Items of group 2		Items of group3	
Item number	Results	Item number	Results
26	$S_4\succcurlyeq S_2=S_3\succcurlyeq S_1$	46	$S_2\succcurlyeq S_5=S_3=S_7=S_4\succcurlyeq S_1=S_6$
7	$S_1\succcurlyeq S_4=S_5\succcurlyeq S_3\succcurlyeq S_2$	33	$S_1=S_7=S_4\succcurlyeq S_5=S_6=S_3\succcurlyeq S_2$
51	$S_4=S_2\succcurlyeq S_3\succcurlyeq S_1$	22	$S_1\succcurlyeq S_4\succcurlyeq S_5=S_3\succcurlyeq S_2$
28	$S_2=S_3\succcurlyeq S_4=S_5\succcurlyeq S_1$	1	$S_2\succcurlyeq S_3=S_1=S_5\succcurlyeq S_4$
11	$S_5\succcurlyeq S_3\succcurlyeq S_2=S_6\succcurlyeq S_1\succcurlyeq S_4$	61	$S_2=S_5\succcurlyeq S_1=S_3=S_4\succcurlyeq S_6$
44	$S_2=S_4\succcurlyeq S_3\succcurlyeq S_1$	31	$S_4=S_1=S_5\succcurlyeq S_2\succcurlyeq S_3$
19	$S_1\succcurlyeq S_4=S_5\succcurlyeq S_3\succcurlyeq S_2$	17	$S_1=S_3\succcurlyeq S_4=S_2\succcurlyeq S_5$

Trial execution of this method for EMERSUN as a big Industrial Company within a quarterly analogy had some noticeable effects where its foremost effects are given in Table 19.

Table 19- Model execution effects

	One year before method execution	After model execution	Reduction ratio	Remarks
Supply cost (Billion Rials.)	800	752	0.06	Regardless of 25% inflation
Qualitative Returns	65352	32190	50%	Given that importation control rules was enforced very rigidly for return

9. Conclusion

Intense competitive pressure forces many organizations to provide products and services for costumer, faster, cheaper and with higher quality than other competitors. Managers also have to understand that in order to gain competitive advantages and achieving supply chain goals they should pay attention to decisions related to evaluation and selection of suppliers. In this paper an analytical approach in the field of supplier's evaluation and selection has developed, which aims at minimizing cost and risk of supply items that an organization requirements. In this paper a group decision making model has proposed to evaluate and select suppliers using Kraljic matrix, fuzzy AHP and fuzzy VIKOR.

This approach has been designed for managers based on minimizing simultaneously supply risk and cost. This model sets two pivotal strategic criteria, risk and cost, basis of evaluating supplier. The combination of fuzzy set theory and this model will overcome uncertainty and ambiguity in decision making process.

At first, strategic items of producer organization identified using Kraljic matrix and based on prioritizing two dimensions (1) cost ratio (2) supply risk. Then, the model will be extended for evaluating and selecting of suppliers of items of this group. Using Kraljic matrix and linguistic variables have been proposed, both risk and cost criteria are weighted. Hence the proposed approach reduces dependence of decision makers and makes decisions more rational. Then we use fuzzy AHP method for weight assignment of sub criteria, defined for supply risk, and implement VIKOR method for supplier ranking for each strategic item.
Recommendations for future research:

- This decision making model can be used in other areas of managerial decision making such as project selection and location selection.
- Proposed method can be implemented and improved for evaluating other industries.
- Other categorizing approaches would be use for classifying items and suppliers and develop the model depend upon it.
- Other categorizing approaches would be use for classifying items and suppliers and identify important, strategic, value added and relevant to organizations criteria and develop model based on them.

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