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Supplier Selection in Textile Industry Using Fuzzy MADM

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Abstract: Supplier selection, Inventory control and economy order quantity is always 1 of the most important issues in manufacturing industries and textile industry is no exception. Unfortunately traditional performances of some managers in this industry have led to bankrupting and closuring of some factories. In this study, we use fuzzy Delphi, fuzzy AHP and VIKOR under fuzzy environment as a decision tool to supplier selection. The aim of this study is develop a model with high reliability for supplier selection in textile industry. From fuzzy Delphi we extracted five essential criteria and with fuzzy AHP we weight these criteria and with VIKOR under fuzzy environment we choose the best suppliers. We construct a questionnaire for fuzzy AHP and VIKOR that it's not needed to notice cost orientation or benefit orientation of criteria. Our finding shows that five criteria; quality, location, cost, trust and delivery are the most effective criteria in textile supplier selection area. According to our proposed method suppliers s_9, s_{15}, s_{16}, s_4, s_5 are the best supplier.

Keywords: Fuzzy logic, fuzzy Delphi, fuzzy AHP, fuzzy VIKOR, supplier selection, textile industry

INTRODUCTION

According to Goffin *et al*. (1997) supplier management is one of the key issues of supply chain management because the cost of raw materials and component parts constitutes the main cost of a product and most of the firms have to spend considerable amount of their sales revenues on purchasing (Goffin *et al*., 1997). The changing nature of the marketplace along Increases and varieties of customer demands, advances of recent technologies in communication and information systems, competition in global environment, decreases in governmental regulations and increases in environmental consciousness have forced companies for focusing on supply chain management (Tracey and Tan, 2001). Nowadays, competitive business environment has forced companies to satisfy customers who demand increasing product variety, lower cost, better quality and faster response (Vondrembse *et al*., 2006).

While the benefits of outsourcing have provided many firms a competitive advantage in the marketplace, there have been corresponding increases in the level of corporate exposure to uncertain events with suppliers. The exposure to risks increased when disparate services were provided by the various trading partners (Sims and Standing, 2002). In today's competitive market proper management of the supply chain is the key to success of every company. Selection of the appropriate supplier is a major requirement for an effective supply chain. According to Patton (1997), supplier evaluation and selection is a key element in the industrial buying process and appears to be one of the major activities of the professional industries. This is because the cost and quality of good and services sold are directly related to the cost and quality of goods and services purchased.

Individual firms no longer compete as autonomous entities but rather by joining a supply chain alliance. Members in the supply chain always forge stronger alliances to compete against other supply chains (Lin and Chen, 2004). Experts believe that supplier selection is one of the most prominent activities of purchasing departments (Xia and Wu, 2007). Supplier selection is a difficult problem for managers because the performances of suppliers are varied based on each criterion (Liu and Hai, 2005).

Supplier selection in industry is a Group Decision-Making (GDM), cross functional problem, frequently solved by a nonprogrammer decision-making process, with long-term commitment for firms. The supplier selection problem deals with defining potential suppliers, selecting the best set of suppliers among them and determining the shipment quantity of each (Weber *et al*., 1991).

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In supplier selection it is very important to choose scientific and rational evaluation Indicators which is the first step to conduct evaluation. Dickson (1966) was one of the original studies in the supplier selection area. He identified 23 criteria for assessing the performance of suppliers based on responses from 170 managers and purchasing agents.

In real life, the modeling of many situations may not be sufficient or exact, as the available data are inexact, vague, imprecise and uncertain by nature (Sarami *et al*., 2009). The aim of this study is to use Fuzzy MADM to identifying critical criteria in textile industry and then select best suppliers according to these criteria. In this study, we use fuzzy Delphi, fuzzy AHP and Fuzzy VIKOR as a decision tool to supplier selection. The fuzzy set theory approaches could resemble human reasoning in use of approximate information and uncertainty to generate decisions. Furthermore, fuzzy logic has been integrated with MADM to deal with vagueness and imprecision of human thought.

Through Fuzzy Delphi Method, the key indicators can be derived. Then a question rises up here and that is how this importance weight could be calculated? For the determination of the relative importance of selection criteria, fuzzy AHP can be used since it is based on pair wise comparisons and allows the utilization of linguistic variables. Although the pair wise comparison approach is the most demanding in terms of solicited input from the experts, it offers maximum insight, particularly in terms of assessing consistency of the experts' judgment. VIKOR focuses on ranking and sorting a set of alternatives against various, or possibly conflicting and non-com- measurable, decision criteria assuming that compromising is acceptable to resolve conflicts. In fuzzy VIKOR, linguistic preferences can easily be converted to fuzzy numbers (Cevikcan *et al*., 2009).

LITERATURE REVIEW

Supplier selection criteria: A supply chain is a network of suppliers, manufacturing plants, warehouses and distribution channels organized to acquire raw materials, convert these raw materials to finished products and distribute these products to customers (Bidhandi *et al*., 2009). During recent years supply chain management and supplier selection process have received considerable attention in the literature. Supplier selection is one of the most critical activities of purchasing management in supply chain and in this process suppliers are reviewed, evaluated and chosen to become a part of the company's supply chain (Sanayei *et al*., 2008; Guo, 2009). Supplier selection has been a focus of academicians and purchasing practitioners since the 1960s (Dickson, 1966; Weber *et al*.,1991).The evolution of the competitive environment has made company competitiveness and survival depend more and more on their suppliers (De Boer *et al*., 2001).

Researchers have applied both qualitative and quantitative approaches in considering supplier selection and there are many studies that discussed the issue of supplier selection (Bhutta and Huq, 2002; Chou and Chang, 2008; Mohammady, 2005; Ramanathan, 2007; Teng and Jaramillo, 2005), most of them focus on price, quality, services, delivery time, supplier location, supplier financial statues and performance. Periodic evaluation of supplier quality is carried out to ensure the meeting of relevant quality standards for all incoming items (Jain *et al*., 2004).

Muralidharan *et al*. (2002) identify some supplier selection criteria such as quality, delivery, price and technical capability.

Briggs (1994) stated that joint development, culture, forward engineering, trust, supply chain management, quality and communication are the key requirements of a supplier partnership, apart from optimum cost. Chao *et al*. (1993) concluded that quality and on time delivery are the most important attributes of purchasing performance.

Bottani and Rizzi (2006) applied service criteria such as breath of service, business experience, characterization of service, compatibility, financial stability, flexibility of service, performance, price, physical equipment and information, quality, strategic attitude, trust and fairness.

Yang and Chen (2006) performed a literature review and an interview with 3 business executives that concluded to 6 qualitative criteria including quality, finances, service, production capacity, design, technological capability and IT infrastructure and to 4 quantitative criteria including turnover, cost, delivery and distance. Kahraman *et al*. (2003) mentioned that selection criteria typically fall into one of 4 categories: supplier criteria, product performance criteria, service performance criteria and cost criteria.

Gill and Ramaseshan (2007) divided supplier selection criteria into 5 parts:

- Relationship commitment
- Product quality
- Price
- Payment facilities
- Brand recognition

Hong *et al*. (2005) defined such criteria which can be used to evaluate whether or not a supplier is capable of delivering the desired product, in the desired quantity

Table1: Supplier selection criteria and frequently of use in several papers

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Quality	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Cost	*	*	*		*	*	*	*	*	*			*	*	*	*	
Delivery	*	*			*	*		*	*	*	*	*		*	*		
Technology ability		*		*				*	*	*				*			*
Service	*	*		*	*		*		*			*	*	*			
Location							*								*		*
Trust										*	*	*					
Integration ability														*			
R & D									*					*			
Flexibility				*	*			*				*	*				
Risk		*							*			*		*			
Past performance							*		*		*			*			
Capacity														*			*
Response to customer				*			*					*	*	*			
Finance							*					*	*	*			*
Facility							*										
Warranties											*						
Brand recognition							*										
Humanitarian treatment														*			

1 (Zhang *et al*., 2009), 2 (Lee, 2009), 3 (Wu *et al*., 2009), 4 (Shen and Yu, 2009), 5 (Chang and Hung, 2010), 6 (Chamodrakas *et al*., 2010), 7 (Tsai *et al*., 2010), 8 (Sanayei *et al*., 2010), 9 (Wu, 2010), 10 (Shemshadi *et al*., 2011), 11 (Liao and Kao, 2011), 12 (Vinodh *et al*., 2011), 13 (Chan *et al*., 2008), 14 (Deng and Chan, 2011), 15 (Aksoy and Öztürk, 2011), 16 (Kara, 2011), 17 (Kilincci and Onal, 2011)

and at the desired time. On the other hand, they defined the criteria that can be used to evaluate profit as price, quality and quantity. We list the number of criteria in Table 1 that were used in previous supplier selection researches.

Supplier selection techniques: Since supplier selection problems usually have several objectives such as maximization of quality or maximization of profit or minimization of cost, the problem can be modeled using mathematical programming. There are exist plethora of research on the supplier selection process. Traditional methodologies of the supplier selection process in the extant literature range from single objective techniques such as the cost-ratio method, linear or mixed integer programming to goal and multi-objective linear programming models (Ghodsypour and O'Brien, 1998; Yan *et al*., 2003).

While several supplier selection methods have been identified and widely applied in the industry, industrialists and academics differ in their approach to the study of methods for supplier selection. Industrialists take a relatively more practical approach than academics.

Lee *et al*. (2001) used only AHP for supplier selection. They determined the supplier selection criteria based on the purchasing strategy and criteria weights by using AHP. Xia and Wu (2007) used an integrated approach of AHP improved by rough sets theory and multi-objective mixed integer programming, which was proposed to simultaneously determine the number of suppliers to employ and the order quantity allocated to these suppliers in the case of multiple sourcing and multiple products, with multiple criteria and with the supplier's capacity constraints.

Haq and Kannan (2006) developed an integrated supplier selection and multi-echelon distribution inventory model for the original equipment manufacturing company in a built-to-order supply chain environment using fuzzy AHP and a genetic algorithm. Chen *et al*. (2006) developed a hierarchy multiple criteria decision- making model based on fuzzy sets theory to deal with the supplier selection problems. Their model uses the concept of TOPSIS to determine the ranking order of all suppliers. There are exists a plethora of research on the supplier selection process.

Wang *et al*. (2004) have developed a decision-based methodology for supply chain design that a plant manager can use to select suppliers. This methodology derived from the techniques of Analytical Hierarchy Process (AHP) and pre-emptive goal programming.

The researches and applications in recent years are: applied analytical hierarchy process (Kokangul and Susuz, 2009), used analytic network process (Hsu and Hu, 2009; Wu *et al*., 2009), proposed neural network (Lee and Ou-Yang, 2009), proposed a fuzzy model (Lee *et al*., 2009), proposed a hybrid method (Ha and Krishnan, 2008) and proposed fuzzy hierarchical and

TOPSIS for the supplier selection problem (Wang *et al*., 2009).

Feng *et al*. (2005) proposed a comprehensive evaluation method based on fuzzy decision theory and characteristics of supply chain management for optimal combination and selection among candidate suppliers and outsourced parts.

Chan *et al*. (2008) propose a fuzzy AHP approach for global supplier selection. Chamodrakas *et al*. (2010) use fuzzy AHP to select supplier in electronic sector.

Shemshadi *et al*. (2011) extended the VIKOR method with a mechanism to extract and deploy objective weights based on Shannon entropy concept for supplier selection.

Chen and Wang (2009) provided a more efficient delivery approach for evaluating and assessing possible suppliers/vendors using the fuzzy VIKOR method.

Sanayei *et al*. (2010) proposed a hierarchy MCDM model based on fuzzy sets theory and VIKOR method is proposed to deal with the supplier selection problems in the supply chain system.

Fuzzy logic: Fuzzy set theory first was introduced by Zadeh (1965) to map linguistic variables to numerical variables within decision making processes. Then the definition of fuzzy sets were manipulated to develop Fuzzy Multi-Criteria Decision Making (FMCDM) methodology by Bellman and Zadeh (1970) to resolve the lack of precision in assigning importance weights of criteria and the ratings of alternatives against evaluation criteria.

A fuzzy set is characterized by a membership function, which assigns to each element a grade of membership within the interval [0,1], indicating to what degree that element is a member of the set (Bevilacqua *et al*., 2006). As a result, in fuzzy logic general linguistic terms such as ‘‘bad’’, ‘‘good’’ or ‘‘fair’’ could be used to capture specifically defined numerical intervals.

A tilde ‘‘~’’ will be placed above a symbol if the symbol represents a fuzzy set. A triangular fuzzy number (TFN) $\widetilde{M}$ is shown in Fig. 1. A TFN is denoted simply as (l, m, u). The parameters l,m and u denote the smallest possible value, the most promising value and the largest possible value that describe a fuzzy event (Kahraman *et al*., 2004). When l = m = u, it is a non-fuzzy number by convention (Chan and Kumar, 2007).

Each TFN has linear representations on its left and right side such that its membership function can be defined as (Kahraman *et al*., 2004);

$$\mu_{\widetilde{M}} = \begin{cases} 0, x < l \\ (x-l)/(m-l), l \le x \le m \\ (u-x)/(u-m), m \le x \le u \\ 0, x > u \end{cases} \quad (1)$$

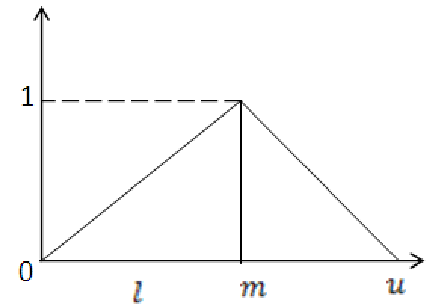

Fig. 1: A triangular fuzzy number, $\widetilde{\boldsymbol{M}}$(Kahraman *et al*., 2004)

$\otimes$: multiply fuzzy numbers, e.g. assuming 2 triangular fuzzy numbers:

$$\tilde{A} = (a_1, b_1, c_1),\ \tilde{B} = (a_2, b_2, c_2)$$
$$\tilde{A} \otimes \tilde{B} = (a_1 \times a_2, b_1 \times b_2, c_1 \times c_2) \quad (2)$$

$\oslash$: divide fuzzy numbers, e.g.: assuming two triangular fuzzy numbers:

$$\tilde{A} = (a_1, b_1, c_1),\ \tilde{B} = (a_2, b_2, c_2)$$
$$\tilde{A} / \tilde{B} = (a_1 / a_2, b_1 / b_2, c_1 / c_2) \quad (3)$$

METHODOLOGY

Our proposed methodology is applied to Textile industry in IRAN in 2011. The main location of this research is industrial unit of yarn cracking of SEMNAN. In addition, in order to increase the reliability of the research the experts’ opinions of YAZD BAF, ARDAKAN textile, IRAN ALYAF and IRAN MERINOOS were used. According to study of production line of this industrial unit the essential primary materials, in order to produce the chosen product are; TAPS, Cationic color, Softener, Acetic acid, Disperse and Retarder.

Based on literature review we found 19 criteria that were used in 17 papers on supplier selection. In this study we use an integrated fuzzy Delphi, fuzzy AHP and VIKOR under fuzzy environment for supplier selection. Firstly we used fuzzy Delphi method to extract critical criteria in supplier selection. The importance weights of various criteria and the ratings of qualitative criteria are considered as linguistic variables. In order to evaluate the weights of criteria that were obtained by fuzzy Delphi method, fuzzy AHP was used. We then evaluated the suppliers by fuzzy VIKOR.

Table 2: Linguistic variables for importance of each criterion

Absolutely appropriate	(9, 10, 10)
Appropriate	(7, 9, 10)
Slightly appropriate	(5, 7, 9)
Neutral	(3, 5, 7)
Slightly inappropriate	(1, 3, 5)
Inappropriate	(0, 1, 3)
Absolutely inappropriate	(0, 0, 1)

Fuzzy delphi: Murry *et al*. (1985) proposed the concept of integrating the traditional Delphi Method and the fuzzy theory to improve the vagueness of the Delphi Method. Membership degree is used to establish the membership function of each participant. Ishikawa *et al*. (1993) further introduced the fuzzy theory into the Delphi Method and developed max–min and fuzzy integration algorithms to predict the prevalence of computers in the future. In this study we used Fuzzy Delphi Method was proposed by Ishikawa *et al*. (1993) and it was derived from the traditional Delphi technique and fuzzy set theory.

Noorderhaben (1995) indicated that applying the Fuzzy Delphi Method to group decision can solve the fuzziness of common understanding of expert opinions. In this study we use ten experts to extract the critical criteria of supplier selection.

The FDM steps are as follows:

- **Collect opinions of decision group:** Find the evaluation score of each alternate factor's significance given by each expert by using linguistic variables that it is considered from Table 2.

- **Set up triangular fuzzy numbers:** Calculate the evaluation value of triangular fuzzy number of each alternate factor given by experts, find out the significance triangular fuzzy number of the alternate factor. This study used the geometric mean model of mean general model proposed by Klir and Yuan (1995) for FDM to find out the common understanding of group decision.

The computing formula is illustrated as follows: Assuming the evaluation value of the significance of No. j element given by No.i expert of n experts is $\widetilde{w} = (a_{ij}, b_{ij}, c_{ij})$, i = 1, 2 ,…, n, j = 1, 2 ,…, m. Then the fuzzy weighting $\widetilde{w}$ of No j Element is $\widetilde{w}_{ij} = (a_{ij}, b_{ij}, c_{ij})$, j = 1,2,…,m .

Among which $a_j = min\{a_{ij}\}$,

$$b_j = \frac{1}{n}\sum_{i=1}^{n} b_{ij},\ c_{ij} = max\{c_{ij}\} \tag{4}$$

Defuzzification: Use simple center of gravity method to defuzzify the fuzzy weight $\widetilde{w_{ij}}$ of each alternate element to definite value Sj , the followings are obtained:

$$S_j = \frac{a_j + 4b_j + c_j}{6},\ j = 1, 2, ..., M \tag{5}$$

Screen evaluation indexes: Finally proper factors can be screened out from numerous factors by setting the threshold a. The principle of screening is as follows:

If $Sj \geq \alpha$, then No. j factor is the evaluation index.
If $Sj < \alpha$, then delete No. j factor.

For the threshold value r, the 80/20 rule was adopted with r set as 0.8. This indicated that among the factors for selection, ''20% of the factors account for an 80% degree of importance of all the factors''. The selection criteria were:

If MA≥ r = 0.8, this appraisal indicator is accepted.
If MA < r = 0.8, this appraisal indicator is rejected.

Fuzzy AHP: Laarhoven and Pedrycz (1983) proposed the Fuzzy Analytic Hierarchy Process in 1983, which was an application of the combination of Analytic Hierarchy Process (AHP) and Fuzzy Theory. The linguistic scale of traditional AHP method could express the fuzzy uncertainty when a decision maker is making a decision. Therefore, FAHP converts the opinions of experts from previous definite values to fuzzy numbers and membership functions, presents triangular fuzzy numbers in paired comparison of matrices to develop FAHP, thus the opinions of experts approach human thinking model, so as to achieve more reasonable evaluation criteria.

Laarhoven and Pedrycz (1983) proposed the FAHP, which is to show that many concepts in the real world have fuzziness. Therefore, the opinions of decision makers are converted from previous definite values to fuzzy numbers and membership numbers in FAHP, so as to present in FAHP matrix.

The steps of this study based on FAHP method are as follows:

- **Determine problems:** Determine the current decision problems to be solved, so as to ensure future analyses correct; this study discussed the ''evaluation criteria for verification of supplier selection criteria".
- **Set up hierarchy architecture:** Determine the evaluation criteria having indexes to be the criteria layer of FAHP, for the selection of evaluation criteria, relevant criteria and feasible schemes can

be found out through reading literatures. This study screened the important factors conforming to target problems through FDM investigating experts' opinions, to set up the hierarchy architecture.

- Construct pair wise comparison matrices among all the elements/criteria in the dimensions of the hierarchy system. Assign linguistic terms to the pair wise comparisons by asking which is the more important of each two dimensions, as following matrix $\tilde{A}$:

$$\tilde{A}=\begin{pmatrix} 1 & \tilde{a}_{21} & \cdots & \tilde{a}_{21} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{21} \\ & & & \\ \tilde{a}_{21} & \tilde{a}_{21} & \cdots & 1 \end{pmatrix} = \begin{pmatrix} 1 & \tilde{a}_{21} & \cdots & \tilde{a}_{21} \\ \frac{1}{\tilde{a}_{21}} & 1 & \cdots & \tilde{a}_{21} \\ & & & \\ \frac{1}{\tilde{a}_{21}} & \frac{1}{\tilde{a}_{21}} & \cdots & 1 \end{pmatrix}$$

where,

$$\tilde{a}_{ij}\begin{cases} \tilde{9}^{-1},\tilde{8}^{-1},\tilde{7}^{-1},\tilde{6}^{-1},\tilde{5}^{-1},\tilde{4}^{-1},\tilde{3}^{-1},\tilde{2}^{-1},\tilde{1}^{-1},\tilde{1},\tilde{2},\tilde{3},\tilde{4},\tilde{5},\tilde{6},\tilde{7},\tilde{8},\tilde{9} & i \neq j \\ 1 & i = j \end{cases}$$

- To use geometric mean technique to define the fuzzy geometric mean and fuzzy weights of each criterion by Hsieh *et al*. (2004):

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \ldots \otimes \tilde{a}_{in}) \tag{6}$$

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \ldots \oplus \tilde{r}_n)^{-1} \tag{7}$$

where, a_{ij} is fuzzy comparison value of dimension i to criterion j, thus, $\tilde{r}_i$ is a geometric mean of fuzzy comparison value of criterion i to each criterion. $\tilde{w}_i$ is the fuzzy weight of the ith criterion, can be indicated by a TFN, $\tilde{w}_i = (lw_i, mw_i, uw_i)$. The lw_i, mw_i and uw_i stand for the lower, middle and upper values of the fuzzy weight of the ith dimension.

Fuzzy VIKOR method: Opricovic (1998) and Opricovic and Tzeng (2002) developed VIKOR, the Serbian name: VlseKriterijumska Optimizacija I Kompromisno Resenje, means multi-criteria optimization and compromise solution. The VIKOR method was developed for multi-criteria optimization of complex systems (Opricovic and Tzeng, 2004). VIKOR focuses on ranking and sorting a set of alternatives against various, or possibly conflicting and non-com-measurable, decision criteria assuming that compromising is acceptable to resolve conflicts. Similar to some other MCDM methods like TOPSIS, VIKOR relies on an aggregating function that represents closeness to the ideal, but the unlike TOPSIS, introduces the ranking index based on the particular measure of closeness to the ideal solution and this method uses linear normalization to eliminate units of criterion functions (Opricovic and Tzeng, 2004). In fuzzy VIKOR, it is suggested that decision makers use linguistic variables to evaluate the ratings of alternatives with respect to criteria. Table 3 gives the linguistic scale for the evaluation of alternatives. Assuming that a decision group has K people, the ratings of alternatives with respect to each criterion can be calculated as in Eq. 6 (Wang *et al*., 2006):

Table 3: Linguistic variables for importance of each alternative

Absolutely appropriate	AAP	(9, 10, 10)
Appropriate	AP	(7, 9, 10)
Slightly appropriate	SAP	(5, 7, 9)
Neutral	N	(3, 5, 7)
Slightly inappropriate	SINAP	(1, 3, 5)
Inappropriate	INAP	(0, 1, 3)
Absolutely inappropriate	AINAP	(0, 0, 1)

$$\tilde{x}_{ij} = \frac{1}{k}[\tilde{x}_{ij}^1 \oplus \tilde{x}_{ij}^2 \oplus \ldots \oplus \tilde{x}_{ij}^k] \tag{8}$$

where, $\tilde{x}_{ij}^k$ is the rating of the kth decision maker for ith alternative with respect to jth criterion. After obtaining the weights of criteria and fuzzy ratings of alternatives with respect to each criterion, we can now express the fuzzy multi-criteria decision-making problem in matrix format as:

$$\tilde{D} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{pmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & & & \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{pmatrix} \end{array}$$

$$\tilde{W} = [w_1, w_2, \ldots, w_n],\ j = 1,2,\ldots,n$$

Various defuzzification strategies which are defined as the process converting a fuzzy number into a crisp value were suggested. In this study, graded mean integration approach is used. According to the graded mean integration approach, for triangular fuzzy numbers, a fuzzy number $\tilde{C} = (c_1, c_2, c_3)$ can be transformed into a crisp number by employing the below equation (Yang and Chin, 2006):

$$P(\tilde{C}) = C = \frac{c_1 + 4c_2 + c_3}{6} \tag{9}$$

where, $\tilde{x}_{ij}$ is the rating of the alternative A_i with respect to criterion $j(i, e, C_j)$ and $\tilde{w}_j$ denotes the importance weight of C_j. Next step is to determine the best value $(BV, \tilde{f}_j^*)$ and worst value $(WV, \tilde{f}_j^-)$ of all criterion functions:

$$\tilde{f}_j^* = \max_i \tilde{x}_{ij}\ , \quad \tilde{f}_j^- = \min_i \tilde{x}_{ij}$$

Then, the values $\frac{\tilde{w}_j(\tilde{f}_j^* - \tilde{f}_j^*)}{(\tilde{f}_j^* - \tilde{f}_j^-)}$, $\tilde{S}_j$ and $\tilde{R}_j$ are computed in order to obtain:

$$\tilde{S}_j = \sum_{j=1}^{n} \frac{\tilde{W}_j(\tilde{f}_j^* - \tilde{f}_j^*)}{(\tilde{f}_j^* - \tilde{f}_j^-)} \tag{10}$$

$$\tilde{R}_j = \max\left[\frac{\tilde{W}_j(\tilde{f}_j^* - \tilde{f}_j^*)}{(\tilde{f}_j^* - \tilde{f}_j^-)}\right] \tag{11}$$

Where $\tilde{S}_i$ refers to the separation measure of A_i from the best value and $\tilde{R}_j$ to the separation measure of A_i from the worst value.
In the next step $\tilde{S}_i^*$, ,$\tilde{S}_i^-$, $\tilde{R}_i^*$, $\tilde{R}_i^-$ and $\tilde{Q}_j$ values are calculated:

$$\tilde{S}_i^* = \min_i \tilde{S}_i, \tilde{S}_i^- = \max_i \tilde{S}_i, \tilde{R}_i^* = \min_i \tilde{R}_i,$$
$$\tilde{R}_i^- = \min_i \tilde{R}_i \tag{12}$$

$$\tilde{Q}_i = v\left[\frac{\tilde{S}_i - \tilde{S}^*}{\tilde{S}^- - \tilde{S}^*}\right] + (1-v)\left[\frac{\tilde{R}_i - \tilde{R}^*}{\tilde{R}^- - \tilde{R}^*}\right] \tag{13}$$

The index $\min_i \tilde{S}$ and $\min_i \tilde{R}$ are related to a maximum majority rule and a minimum individual regret of an opponent strategy, respectively. As well, v is introduced as weight of the strategy of the maximum group utility, usually v is assumed to be 0.5. In this study we assumed that v is 0.5. Next task is the calculating $\tilde{Q}_i$ and ranking the alt ernatives by the index $\tilde{Q}_i$. Finally, the best alternative with the minimum of $\tilde{Q}_i$ is determined.

EVALUATING MODEL APPLICATION

Stage one: Reviewing relevant literature of supplier selection criteria and proposing important criteria:
19 criteria for supplier selection based on relevant literature are proposed.

Stage two: Screen important criteria by Fuzzy Delphi Method:

First a FDM interview table is setup and second interview was done with ten experts from textile industry. Five criteria were extracted from this stage (Table 4).

Table 4: List of criteria and definition

Criteria	Definition
C_1: Quality	To provide a high-quality product, supplier should have a quality system including quality assurance, quality control procedures, quality control charts, documentation, continuously quality improvement, etc.
C_2: Cost	Cost of product is a high percentage of in total cost of purchasing. Therefore purchasing department wants to purchase the product with minimum price to decrease the total cost.
C_3: Location	The geographical distance from supplier to factory.
C_4: Delivery	The duration of time from setting an order to the receipt of the order. The ability to follow the predefined delivery schedule. The consistency in meeting delivery deadlines. The consistency in meeting delivery deadlines
C_5: Trust	The amount of competency and integrity that is exists between supplier and factory.

Table 5: Linguistic variables for weight of each criterion

Extremely strong	(9, 9, 9)
Intermediate	(7, 8, 9)
Very strong	(6, 7, 8)
Intermediate	(5, 6, 7)
Strong	(4, 5, 6)
Intermediate	(3, 4, 5)
Moderately strong	(2, 3, 4)
Intermediate	(1, 2, 3)
Equally strong	(1, 1, 1)

Stage three: The weights of evaluation criteria We adopt fuzzy AHP method to evaluate the weights of different criteria for the performance of technology selection criteria. Following the construction of fuzzy AHP model, it is extremely important that experts fill the judgment matrix.

According to the committee with ten representatives about the relative important of criteria, then the pair wise comparison matrices of criteria will be obtained. We apply the fuzzy numbers defined in Table 5. We transfer the linguistic scales to the corresponding fuzzy numbers. Computing the elements of synthetic pair wise comparison matrix by using the geometric mean method suggested by Buckley (1985) that is:

$$\tilde{a}_{ij} = \left(\tilde{a}_{ij}^1 \otimes \tilde{a}_{ij}^2 \otimes .... \otimes \tilde{a}_{ij}^{10}\right)^{\frac{1}{10}} \tag{14}$$

The synthetic pair wise comparison matrices of the ten representatives will be constructed as follows Table 6:

To calculate the fuzzy weights of criteria, the computational procedures were performed as follows:

$$\tilde{r}_1 = \left(\tilde{a}_{11} \otimes \tilde{a}_{12} \otimes \tilde{a}_{13} \otimes \tilde{a}_{14} \otimes \tilde{a}_{15}\right)^{\frac{1}{5}}$$

Table 6: Fuzzy comparison matrix for the relative importance of criteria

	C1			C2			C3			C4			C5		
C1	1	1	1	1.217	1.783	2.352	4.644	5.633	6.554	0.822	1.217	1.719	2.048	2.687	3.438
C2	0.425	0.561	0.822	1	1	1	3.031	4.076	5.102	0.461	0.668	0.944	1.355	1.864	2.383
C3	0.157	0.184	0.225	0.196	0.245	0.330	1	1	1	0.149	0.176	0.218	0.370	0.425	0.514
C4	0.582	0.822	1.217	1.059	1.496	2.169	4.580	5.674	6.732	1	1	1	1.888	2.687	3.366
C5	0.291	0.372	0.488	0.420	0.536	0.738	1.947	2.352	2.702	0.297	0.372	0.530	1	1	1

Table 7: Ratings of the 20 suppliers by the decision makers under the various criteria

Supplier	Decision maker	C1	C2	C3	C4	C5	Supplier	Decision maker	C1	C2	C3	C4	C5
	D1	AP	SAP	AP	AP	AAP		D1	AP	SAP	SAP	AAP	AP
S1	D2	SAP	SAP	SAP	AP	AP	S11	D2	SAP	SAP	AP	AP	SAP
	D3	SAP	SAP	AP	SAP	AP		D3	SAP	AP	SAP	AAP	SAP
	D1	AP	SAP	AP	AP	AAP		D1	AP	AP	N	SAP	AP
S2	D2	AP	SAP	AP	AAP	SAP	S12	D2	SAP	SAP	SAP	AP	AAP
	D3	SAP	AP	SAP	SAP	AP		D3	SAP	AP	SAP	SAP	SAP
	D1	AP	AP	AP	SAP	AP		D1	SAP	SAP	N	AP	AP
S3	D2	AP	SAP	AP	AP	SAP	S13	D2	SAP	AP	SAP	AP	SAP
	D3	N	AP	AP	SAP	SAP		D3	SAP	SAP	AP	AP	SAP
	D1	AP	SAP	SAP	SAP	AP		D1	SAP	SAP	N	AP	N
S4	D2	AP	AP	N	SAP	SAP	S14	D2	SAP	AP	AP	AP	SAP
	D3	SAP	SAP	SAP	SAP	AAP		D3	AP	SAP	N	SAP	AP
	D1	AP	SAP	SAP	N	SAP		D1	AP	SAP	SAP	N	AAP
S5	D2	AP	SAP	SAP	SAP	AAP	S15	D2	AP	AP	N	SAP	SAP
	D3	SAP	AP	AP	SAP	SAP		D3	AP	SAP	SAP	AAP	AP
	D1	AP	AP	AAP	SAP	SAP		D1	AP	AP	SAP	SAP	AP
S6	D2	SAP	SAP	SAP	AP	SAP	S16	D2	AAP	N	AP	AP	SAP
	D3	SAP	SAP	AP	AAP	SAP		D3	SAP	AP	AP	AP	SAP
	D1	AP	SINAP	AP	SAP	SAP		D1	N	N	N	AP	AP
S7	D2	SAP	SAP	SAP	N	SAP	S17	D2	SAP	SINAP	SINAP	AP	AP
	D3	SAP	AP	AP	SAP	SAP		D3	AP	SAP	N	SAP	SAP
	D1	N	AP	AP	N	SAP		D1	SAP	SAP	AP	AP	AP
S8	D2	SAP	N	AP	SAP	SAP	S18	D2	AP	SAP	N	SAP	AP
	D3	SAP	AP	AP	AP	N		D3	AP	SAP	AAP	AP	AP
	D1	AP	N	AP	AP	AP		D1	SAP	AP	N	AP	N
S9	D2	AAP	INAP	SAP	AP	AAP	S19	D2	AP	N	SAP	SAP	SAP
	D3	AP	N	SAP	AP	SAP		D3	SAP	SAP	SAP	AAP	SAP
	D1	AP	N	SAP	AP	SAP		D1	AP	N	SAP	SAP	AP
S10	D2	SAP	SAP	SAP	SAP	SAP	S20	D2	SAP	SAP	N	SAP	SAP
	D3	AP	SAP	SAP	SAP	AP		D3	SAP	SAP	SAP	SAP	SAP

$$\tilde{r}_i = ((1,1,1) \otimes (1.217,1.783,2.352) \otimes (4.644,5.633,6.554) \otimes (0.822,1.217,1.719) \otimes (2.048,2.687,0.438))^{\frac{1}{5}} = (1.569,2.01,2.465)$$

$$\tilde{r}_2 = (0.958,1.233,1.566) \quad \tilde{r}_3 = (0.279,0.321,0.384)$$

$$\tilde{r}_4 = (1.397,1.797,2.266) \quad \tilde{r}_5 = (0.589,0.706,0.876)$$

For the weight of each criterion, they can be done as follows:

$$\tilde{w}_1 = \tilde{r}_1 \otimes \left(\tilde{r}_1 \oplus \tilde{r}_2 \oplus \tilde{r}_3 \oplus \tilde{r}_4 \oplus \tilde{r}_5\right)^{-1} \quad \tilde{w}_1 = (0.208, 0.331, 0.515),$$

$$\tilde{w}_1 = (0.127, 0.203, 0.327), \tilde{w}_1 = (0.037, 0.053, 0.08),$$

$$\tilde{w}_1 = (0.185, 0.296, 0.473), \tilde{w}_1 = (0.078, 0.116, 0.183)$$

Evaluating suppliers by fuzzy VIKOR: In this stage we adopt fuzzy VIKOR to evaluate the suppliers. This study focuses on evaluating the values of twenty potential suppliers. First we Construct the fuzzy-decision matrix and choose the appropriate linguistic variables for the alternatives with respect to criteria. The evaluator has his own range for the linguistic variables employed in this study according to his subjective judgments.

The evaluator then adopted linguistic terms (Table 3), including ‘‘very good”, ‘‘good”, ‘‘medium good”, ‘‘fair” , ‘‘medium poor ”, “poor” and “very poor” to express his opinion about the rating of each suppliers regarding each criteria. A committee of three decision makers, D1; D2 and D3, has been formed to select the most suitable suppliers (Table 7). Then the expressions have been changed to fuzzy triangular numbers (Table 8).

With Eq. (8, 9), separation measure from the fuzzy best value $\tilde{S}_i$, separation measure from the fuzzy worst value $\tilde{R}_i$ (Table 9) and then $\tilde{S}_i^*$, ,$\tilde{S}_i^-$, $\tilde{R}_i^*$ and $\tilde{R}_i^-$ values are computed as in Table 10.

Table 8: Fuzzy values for decision matrix

	C1			C2			C3			C4			C5		
S1	5.67	7.67	9.33	5.00	7.00	9.00	6.33	8.33	9.67	6.33	8.33	9.67	7.67	9.00	10.00
S2	6.33	8.33	9.67	5.67	7.67	9.33	6.33	8.33	9.67	7.00	8.33	9.67	7.00	8.33	9.67
S3	5.67	7.67	9.00	6.33	8.33	9.67	7.00	9.00	10.00	5.67	7.67	9.33	5.67	7.67	9.33
S4	6.33	8.33	9.67	5.67	7.67	9.33	4.33	6.33	8.33	5.00	7.00	9.00	7.00	8.33	9.67
S5	6.33	8.33	9.67	5.67	7.67	9.33	5.67	7.67	9.33	4.33	6.33	8.33	6.33	7.67	9.33
S6	5.67	7.67	9.33	5.67	7.67	9.33	7.00	8.33	9.67	7.00	8.33	9.67	5.00	7.00	9.00
S7	5.67	7.67	9.33	4.33	6.33	8.00	6.33	8.33	9.67	4.33	6.33	8.33	5.00	7.00	9.00
S8	4.33	6.33	8.33	5.67	7.67	9.00	7.00	9.00	10.00	5.00	7.00	8.67	4.33	6.33	8.33
S9	7.67	9.00	10.00	2.00	3.67	5.67	5.67	7.67	9.33	7.00	9.00	10.00	7.00	8.33	9.67
S10	6.33	8.33	9.67	4.33	6.33	8.33	5.00	7.00	9.00	5.67	7.67	9.33	5.67	7.67	9.33
S11	5.67	7.67	9.33	5.67	7.67	9.33	5.67	7.67	9.33	8.33	9.00	10.00	5.67	7.67	9.33
S12	5.67	7.67	9.33	6.33	8.33	9.67	4.33	6.33	8.33	5.67	7.67	9.33	7.00	8.33	9.67
S13	5.00	7.00	9.00	5.67	7.67	9.33	5.00	7.00	8.67	7.00	9.00	10.00	5.67	7.67	9.33
S14	5.67	7.67	9.33	5.67	7.67	9.33	4.33	6.33	8.00	6.33	8.33	9.67	5.00	7.00	8.67
S15	7.00	9.00	10.00	5.67	7.67	9.33	4.33	6.33	8.33	5.67	7.00	8.67	7.00	8.33	9.67
S16	7.00	8.33	9.67	5.67	7.67	9.00	6.33	8.33	9.67	6.33	8.33	9.67	5.67	7.67	9.33
S17	5.00	7.00	8.67	3.00	5.00	7.00	2.33	4.33	6.33	6.33	8.33	9.67	6.33	8.33	9.67
S18	6.33	8.33	9.67	5.00	7.00	9.00	6.33	7.67	9.00	6.33	8.33	9.67	7.00	9.00	10.00
S19	5.67	7.67	9.33	5.00	7.00	8.67	4.33	6.33	8.33	7.00	8.33	9.67	4.33	6.33	8.33
S20	5.67	7.67	9.33	4.33	6.33	8.33	4.33	6.33	8.33	5.00	7.00	9.00	5.67	7.67	9.33

Table 9: Separation measures of suppliers from the fuzzy best and fuzzy worst values

Supplier	$\tilde{S}_i$			$\tilde{R}_i$			Supplier	$\tilde{S}_i$			$\tilde{R}_i$		
S1	-0.551	0.270	1.352	-0.257	0.166	0.669	S11	-0.711	0.274	1.684	-0.322	0.166	0.762
S2	-0.521	0.181	1.263	-0.226	0.083	0.644	S12	-0.714	0.340	1.740	-0.322	0.166	0.762
S3	-0.537	0.286	1.406	-0.235	0.165	0.684	S13	-0.758	0.366	1.967	-0.359	0.249	0.835
S4	-0.526	0.282	1.304	-0.226	0.083	0.644	S14	-0.737	0.380	1.900	-0.322	0.166	0.762
S5	-0.521	0.324	1.290	-0.226	0.083	0.644	S15	-0.643	0.274	1.480	-0.249	0.000	0.617
S6	-0.564	0.311	1.311	-0.257	0.166	0.669	S16	-0.672	0.242	1.626	-0.274	0.084	0.515
S7	-0.547	0.480	1.350	-0.257	0.166	0.669	S17	-0.751	0.593	2.002	-0.337	0.248	0.854
S8	-0.586	0.565	1.441	-0.296	0.331	0.733	S18	-0.678	0.233	1.739	-0.286	0.083	0.690
S9	-0.458	0.244	1.110	-0.186	0.000	0.460	S19	-0.750	0.449	1.838	-0.322	0.166	0.762
S10	-0.532	0.317	1.348	-0.226	0.083	0.644	S20	-0.770	0.550	1.842	-0.322	0.166	0.762

Table 10: $\tilde{S}_i^*$, $\tilde{S}_i^-$, $\tilde{R}_i^*$ and $\tilde{R}_i^-$ values

$\tilde{S}_i^*$	-0.458	0.244	1.110
$\tilde{S}_i^-$	-0.751	0.593	2.002
$\tilde{R}_i^*$	-0.186	0.000	0.460
$\tilde{R}_i^-$	-0.337	0.248	0.854

In the next step, using Eq. 12, $\tilde{S}_i^*$, $\tilde{S}_i^-$, $\tilde{R}_i^*$ and $\tilde{R}_i^-$ fuzzy values are calculated (Table 10).

Then, using Eq. (11), $\tilde{Q}_i$ values are computed. In the calculations, weight of the strategy of the maximum group utility (v) is assumed to be 0.5. Finally, values are defuzzified via graded mean integration method Eq. (13) and ranked according to Q_i index values. Table 11 gives the results of the fuzzy VIKOR analysis.

According to Table 11, 5 suppliers (s_9, s_{15}, s_{16}, s_4, s_5), are the most appropriate suppliers.

CONCLUSION

Supply chain management is an essential ingredient of business practices. In this context, the supplier selection process gains extreme importance. Many researchers and practitioners have focused their work on supplier selection in supply chain management area and deployed a wide range of scientific and technical techniques to enhance efficiency and flexibility of the supply networks and various approaches are available for supplier selection.

In general, supplier evaluation and selection problems are vague and uncertain and so fuzzy set theory helps to convert DM preferences and experiences into meaningful results by applying linguistic values to measure each criterion with respect

Table 11: Fuzzy VIKOR analysis results

Supplier	$\tilde{Q}_i$			Q_i	Rank	Supplier	$\tilde{Q}_i$			Q_i	Rank
S1	-5.950	0.371	6.050	0.264	8	S11	-6.697	0.373	7.133	0.321	11
S2	-1.397	-0.579	5.778	0.344	12	S12	-7.215	0.469	7.555	0.369	13
S3	-6.149	0.390	6.415	0.305	10	S13	-8.428	0.674	8.856	0.521	18
S4	-5.344	0.214	5.626	0.190	4	S14	-7.722	0.524	8.173	0.425	15
S5	-5.596	0.276	5.749	0.210	5	S15	-5.001	0.034	5.485	0.103	2
S6	-6.146	0.431	6.047	0.271	9	S16	-5.427	0.172	5.571	0.139	3
S7	-7.293	0.676	6.825	0.373	14	S17	-9.954	1.000	9.954	0.667	20
S8	-9.201	1.144	8.185	0.593	19	S18	-5.836	0.141	6.656	0.231	7
S9	-3.924	0	3.924	0	1	S19	-8.068	0.627	8.212	0.442	16
S10	-5.642	0.265	5.888	0.218	6	S20	-8.721	0.774	8.565	0.490	17

to every supplier. In this study, a multi-criteria group decision making model has been developed based on fuzzy set theory to efficiently deal with the ambiguity of the decision making problems in practical cases to select the best supplier.

Our results show that 5 criteria i.e., quality, cost, location, delivery and trust in textile supply chain are so important. On the other hand we applied our model in yarn cracking of SEMNAN to enable this unit to achieve their business objectives in the supply chain practices. According to the results obtained by our decision making model 5 suppliers (s_9,s_{15},s_{16},s_4,s_5) are the most appropriate supplier for SAIPA Company and 5 suppliers (s_{17},s_8,s_{13},s_{20},s_{19}) are the worst.

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